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THE EFFECTS OF FATIGUE ON POSITION DETERMINATION AND COGNITIVE WORKLOAD USING A VISUAL AND 3-DIMENSIONAL AUDITORY DISPLAY

by

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June 2004

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THE EFFECTS OF FATIGUE ON POSITION DETERMINATION AND COGNITIVE WORKLOAD USING A VISUAL AND 3-DIMENSIONAL AUDITORY DISPLAY

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Submitted in partial fulfillment of the
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ABSTRACT

This study compares the effects of a visual and a 3-dimensional auditory display on primary and secondary task performance, mood, and mental workload at incremental levels of sleep deprivation. It is based on a study conducted by the Army Research Laboratory, Cognitive Science Branch, Aberdeen, Maryland, from 12 Marines performing land navigational tasks in two helmet-mounted display (HMD) modes; visual and 3-dimensional auditory, for a 48 hour period. The results indicate that performance under sleep deprivation is significantly impacted in both modalities; however, performance in the primary task was more degraded in the 3-D auditory modality. Additionally, Marines were more likely to experience degraded performance in the secondary task with increased sleep deprivation. The recommendations address the need to design HMDs that will not overburden sensory channels and the concern for military leaders to understand the additional demands imposed on solders in a HMD environment.

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Most importantly, I would like to thank the 12 marines who volunteered to be a part of this study and made this thesis topic possible. As well, many thanks to the 10 soldiers from Natick who demonstrated the mock-up Land Warrior Ensemble through the obstacle course and who freely answered my questions and provided great feedback on their previous involvement in sleep deprivation studies.

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EXECUTIVE SUMMARY

Understanding the complexities of the new age in warfare, the Army and other military components are currently undergoing organizational, doctrinal, and cultural transformations in order to aggressively defend our shores, effectively root out the enemy, and decisively engage and destroy him anywhere in the world on any terrain. The Army has focused on the soldier as the centerpiece of this effort while leveraging technological advances to result in a lethally superior full-spectrum force. Recognizing this human dimension of the Land Warrior System, effective soldier and systems interface of the HMD is critical in obtaining collaborative situational awareness. The design of visual and auditory displays and the proper use of these display modalities in presenting information will have a major impact on soldier performance especially in the presence of fatigue.

The purpose of this study is to gain insight into the effects of incremental levels of sleep deprivation on performance while using visual and 3-dimensional auditory displays during land navigation, and enemy detection tasks. In addition, mood and mental workload measurements were also collected. This study is based on the performance of 12 Marines performing land navigational tasks in two helmet-mounted display modalities for 48 hours of total sleep deprivation simulating sustained operations. The analysis showed that there was a significant difference in the performance of both the primary and secondary task with increased sleep deprivation. There was no significant difference between modalities in the subjects' performance of the secondary task. With increasing levels of sleep deprivation, however, performance of the detection task degraded more sharply in the visual as compared to the auditory modality. Interestingly, after 20 hours of continuous operations, land navigation performance of subjects in the auditory modality was significantly impacted.

Four major recommendations have resulted from this study and are listed below. First, baseline performance for all participants in both visual and auditory

modes is essential to any future study. Secondly, the inclusion of a fully rested control group would significantly strengthen the design of the study. Thirdly, more frequent (e.g., hourly) measurements of performance would be tremendously valuable. If implemented, time series methods could be used to model and potentially forecast performance. Finally, dedicated groups should be assigned to perform either auditory or visual modes. While study designs using within subjects effects are generally more powerful, for future studies it would be preferable to adopt a between groups design. The adoption of this type of design will eliminate the confusion of modality with sleep deprivation and enable researchers to differentiate between these two potentially confounding factors.

It is critical that system designers do not overburden the soldier by developing systems that operate contrary to the human sensory system. It is essential that the HMD for OFW is designed and functions to counterbalance the effects of channel overload in order to achieve optimal performance. Most important, military leadership must be educated on the possible negative ramifications of exposing their solders to HMDs in a sustained operational environment. If not managed properly, the use of HMDs when sleep deprived will lead to degraded performance. This degradation will ultimately undermine the advances in technology and will lessen the combat effectiveness of the military unit.

I. INTRODUCTION

A. OVERVIEW

Understanding the complexities of the new age in warfare, the Army and other military components are currently undergoing organizational, doctrinal, and cultural transformations in order to aggressively defend our shores, effectively root out the enemy, and decisively engage and destroy him anywhere in the world on any terrain. The Army has focused on the soldier as the centerpiece of this effort while leveraging technological advances to result in a lethally superior full-spectrum force. The essential element in this new Land Warrior concept links the soldier into the digital battlefield. This linkage is accomplished by integrating the portrayal of information into a helmet system with voice activation software and multi-spectral vision to provide collaborative situational awareness across the battlespace (OFW AL, 2001).

The Land Warrior System will focus on integrating weapons subsystem components into the soldier system providing visual and acoustic access to computer and sensor information. It will integrate soldier and weapons based night vision capability, providing accurate position data, establishing voice and data transmit/receive capability for critical information exchange requirements, and determining soldier location data for navigation (ORD LW, 2001). Technological advancement in the areas of night vision and thermal devices has pushed the operations feasibility window from twelve hours to twenty four hours. It is postulated that this over-matching capability of real-time collaborative situation awareness will result in complete battlefield dominance. The integration of subsystem components will minimize the difference in day and night operational tempo by providing soldiers and units maneuver control unprecedented in typical limited visibility tactical assaults (ORD LW, 2001).

Recognizing the requirements of humans in the Land Warrior System, effective soldier and systems interface of the helmet mounted display (HMD) is critical in obtaining collaborative situational awareness. Advanced sensor and

display technologies can increase the soldier's knowledge of the battlefield and enhance decision-making, but the benefits that this additional information offers depend upon the soldier's ability to capture, process, and act upon this information, quickly and accurately (Glumm, 1999). Although a completed Land Warrior System is not available for testing, it is essential that an in-depth assessment is conducted on the impact of soldier's performance while operating in a HMD environment as well the impact of sleep deprivation on performance in the Land Warrior System. It is thought that design of visual and auditory displays and the proper use of these display modalities in presenting information will have a major impact on soldier performance and this impact may be even more pronounced in the presence of fatigue (Angus & Hestlegrave, 1985).

This thesis explored the effects of sleep deprivation and circadian cycle on navigation performance, psychological stress, cognitive processing, and workload when position information for navigation was presented in two different display modalities. In one display mode, position information was presented in a 3-D auditory format in which verbal information on distance will be perceived by the listener to emanate from outside his head in the direction which he must travel. In the visual mode, the information was presented inside the HMD on a map of the area of operation. Primary task performance in both modes were time required to complete the course. The secondary task required the subject to continuously monitor the display while navigating and correctly identify friend or enemy units through the Land Navigation Course.

B. BACKGROUND

The soldier-centric concept streamlines information directly to the soldier over a netted communications architecture, resulting in dramatic increases in available information. Equipment for the soldier of tomorrow is designed to allow an operational tempo that is unchanged during day and night missions. The problem of sustained performance is crucial to the success of military forces on the "battlefield of the future" (Hegge, 1982, 1984). Sustained and continuous operations may be necessary to overwhelm the enemy and bring the conflict to

an "end before it began." The emergence of this new social ideology of war has propelled the military into the area of research of sustained operations and sustained performance during combat.

Several studies have been conducted in the aviation community that address the effects of pilot performance while operating in a helmet-mounted display environment. These studies provide a foundation for further research that address the concerns of helmet-mounted displays on the Land Warrior System. The ability to process information quickly and accurately is a key component in the success of providing timely collaborative situation awareness of the battlefield. Effective design of the helmet-mounted display combined with adequate fatigue counter-measures is essential in optimizing sustained performance of future LW Soldiers.

C. PROBLEM STATEMENT

The primary research questions being investigated by this research are:

1. How does sleep deprivation affect primary soldier performance (land navigation) while operating in a HMD environment?

2. How does sleep deprivation affect soldier secondary task performance (enemy detections) while operating in a HMD environment?

3. Are there differences in soldier performance, mood and subjective workload when comparing visual versus 3-D auditory display of information over a 48 hour period of total sleep deprivation?

D. THESIS OVERVIEW

This thesis compared the effects of a visual and a 3-dimensional auditory display on primary and secondary soldier task performance, mood, and mental workload at incremental levels of sleep deprivation. It was based on a study conducted by the Army Research Laboratory, Cognitive Science Branch, Aberdeen, Maryland, from 12 Marines performing land navigational tasks in two helmet-mounted display modes; visual and 3-dimensional auditory, for a 48-hour period. Marines were totally deprived of sleep for a 48-hour period while

conducting land navigation tasks while wearing a helmet-mounted display (HMD) in the two modes. Primary and secondary task performance, mood states and operator mental workload were recorded every four hours over the course of the study.

E. THESIS ORGANIZATION

Chapter II provides a review of the scientific literature germaine to this thesis. The methods used in data collection and preparation are presented in Chapter III. Chapter IV covers the analytical strategy and presents statistical results. Finally, conclusions and recommendations for future research are offered in Chapter V.

II. LITERATURE REVIEW

This chapter examines current land navigation methods used in our military, reviews helmet mounted display technology (both visual and auditory modes), discusses human performance, focusing on situational awareness and mental workload, and reviews the literature on human sleep and fatigue.

A. MILITARY LAND NAVIGATION

Dismounted and mounted soldiers require both continuous and accurate position determination to keep up on today's fluid battlefield. The conventional navigational tool used by all soldiers during their basic military education is the lensatic compass.

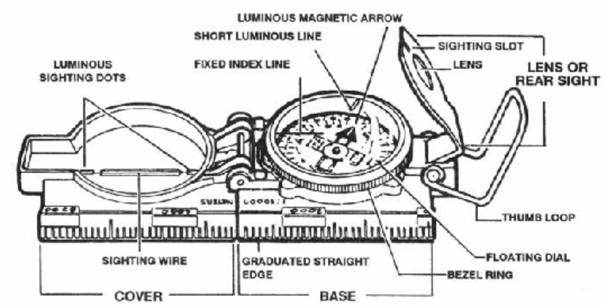

Figure 1. Lensatic Compass (FM 21-26, 2001)

The lensatic compass is a simple instrument to determine direction, although the task of navigating over a distance is a trained skill that many in the military have failed to master. The conventional method of land navigation in the military requires the mastering of several skills to include military map reading, orienteering, and proper compass-hold techniques. Due to its magnetic components, the reliability and accuracy of a lensatic compass is affected when it is used near metal objects or an electrical source. The use of conventional land navigation is a time-demanding practiced skill which requires focused attention and continually demands mental resources to ensure accuracy.

With the complexity of an asymmetrical battlefield, operations in urban environments and precision guide munitions accuracy of target and unit location is paramount. Military operations in urban area require detailed and decentralized execution. In many cases detailed military topographical maps of the area of operations are non-existent or outdated. The use of Global Positioning Systems (GPS) is essential in synchronized execution. The GPS developed for the military by Rockwell International is the called the PLGR, (AN/PSN-11). It is hand-held and when encrypted has an accuracy of $\pm$10 meters. Although the GPS is highly accurate, integrating this capability into the helmet mounted system could decrease soldier's physical workload and provide soldiers real-time positioning, targeting data and navigational guidance on the move.

B. HELMET MOUNTED DISPLAY DEVELOPMENT

Modern helmet mounted (HMD) displays have arrived at their current state through a long development process. Simply defined, an HMD is any information display device which is attached to the head by means of a helmet. By this definition, the first rudimentary HMD was conceptualized in the early part of this century by Albert Bacon Pratt (Marshall, 1989). He patented a helmet-mounted sight system for use by foot soldiers, shown in Figure 2. This device allowed the wearer to aim and fire a head-mounted, semi-automatic gun while keeping both hands free. Aiming was automatic and natural for the marksman as he visually acquired his target, and the weapon was triggered by blowing into a pneumatic tube.

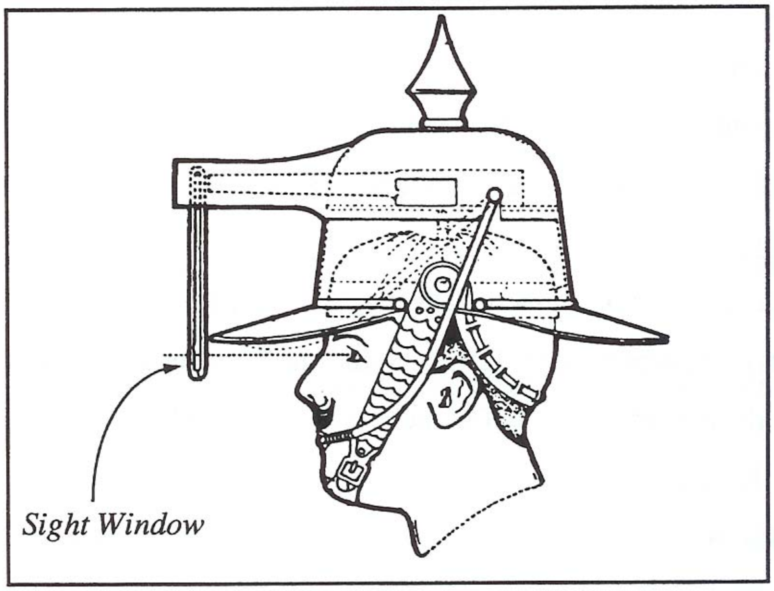

Figure 2. The Helmet Sighting System of A.B. Pratt, circa 1916 (Marshall, 1989)

It was in the aviation cockpit, however, that current HMD technology had its genesis. The original iron gunsights of WWI aviation eventually gave way to reflecting gunsights in WWII. These in turn evolved into a collimated sight display, allowing the pilot to focus on the target and the sight simultaneously. With advancement in electro-optical display technology, additional flight information was incorporated into these displays, giving rise to the modern day head-up display (HUD). The first true HMD, a helmet-mounted computer-driven HUD (alternatively referred to in the literature as an “all-aspect HUD”), was developed in 1960 by the Bell Helicopter Company and was tested in an H-13 Helicopter. It presented the pilot with a 2-D perspective display composed of grid lines to aid in hovering over a spot, and included a vertical thermometer symbol to convey altitude information (Hart, 1988).

Technically, HMDs are a subset of HUDs. While HMDs are an outgrowth of HUD technology and share many characteristics with them, the principles employed in the design of HUD symbols and formats do not necessarily apply to HMDs. In fact, these very principles may serve to confuse and complicate the

user's visual task and increase workload if they are incorporated in HMD design without considerable forethought and evaluation. The primary reason for this confusion is that while a HUD is fixed in the user's field of regard (so that the user can choose to attend to or ignore it), the HMD continues to present symbology and/or imagery throughout the entire field of regard. A user cannot glance away from it. If the visual contents of the HMD are not carefully designed, the user will be subjected to information that is at times unwanted, counterintuitive, disorienting, or difficult to interpret and utilize.

1. HMD Advantages and Disadvantages

There have been numerous studies on the advantage of introducing visual HMD technology into cockpits but little research exists on the use of HMDs for the dismounted soldier. Assenheim (1992) stated that when using HMDs a pilot's situational awareness and ability to see and avoid obstacles at night are enhanced under most viewing conditions. Menu (1986) estimated that the transition between heads-up and heads-down information sources takes 700 msec which can be eliminated if the information is displayed using a head-up configuration. Significant improvements in reaction time and decreased workload result from use of a HUD to retrieve critical information from a heads-down display, Using visual HMDs with enhanced imagery can improve target acquisition and identification, avoiding tactical threat, and enhancing overall safety.

HMDs also have disadvantages resulting from their specific configuration or design. Parts of the HMD may block sectors of the soldier's field of view (FOV). Since symbology is generally fixed in the soldier's FOV, his view of the real world or equipment displays may also be obscured. Proliferation of symbology elements in a confined display area results in high symbology density, or clutter. Manual mode selection of symbol sets and their declutter levels, along with poorly designed symbology and low-fidelity imagery, increase pilot's workload (Assenheim, 1992). Proper helmet fit and alignment of HMD optical

elements are critical to system performance, but operational experience has shown that both can be difficult to achieve and maintain.

2. HMD Types

Typical HMD systems components include:

- An image source, usually a miniature cathode ray tube (CRT)
- A lens system for proper focus and to project the image onto a semi-transparent combiner lens
- A head tracking apparatus which is used to align a remote sensors' line of sight with that of the soldier
- Sensor(s) (e.g., FLIR, Low Light Television, Targeting IR, NVG, and UAV)
- A computer- driven symbol generator
- Displays information on navigation, systems, weapons, target acquisition and identification, obstacle avoidance, virtual switching, virtual training, and warning annunciation, as well as sensor imagery (Haworth, 1993).

HMDs fall into three broad classes: monocular, dual ocular, and auditory. Each will be reviewed in the following section.

a. Monocular HMDs

Monocular displays use a single image source and one set of optics to present imagery to one eye. They are characterized by low weight and small volume. Optical alignment is relatively uncomplicated. One eye always remains adapted to the ambient lighting condition, which may be helpful in the event of an HMD failure or transition to alternate displays. However, it is unnatural for the brain to process different images from each eye simultaneously. This condition leads to binocular suppression and rivalry which are major drawbacks to monocular systems (Wells, 1992). For daytime use, monocular displays are

adequate and may even be preferable since dual ocular systems induce a disparity in convergence between close-in objects and the collimated display (Bull, 1990).

The best known and best-documented monocular HMD is the Integrated Helmet and Display Sighting System (IHADSS) designed for and incorporated in the Army AH-64 Apache attack helicopter. The IHADSS has been operational since 1984. It provides visual imagery for map-of-the-earth flights at night and in low visibility, as well as symbology for flight, target detection and identification, weapons aiming, and systems and weapons status. Electro-optical display technology available in the early 1980s dictated a monocular format for IHADSS, mainly due to concerns about weight and inexperience with dual ocular designs.

Pilots have experienced major difficulties with monocular design of IHADSS and dismounted soldiers are likely to experience the same difficulties. As mentioned before, binocular rivalry occurs when the left and right eyes receive sufficiently dissimilar inputs. The brain often manages image disparity by suppressing one of the images; the pilot cannot always exercise volitional control over this reflex. This problem may be particularly evident as a mission progresses and fatigue or stress levels increase.

The technology used in IHADSS is the basis for the Land Warrior HMD system design. The IHADSS presents the user with a variety of dissimilar inputs to the two eyes: color, resolution, FOV, motion, brightness, and image content (Rash, 1992). These differences are most pronounced during conditions of low visibility or darkness. The brightness of the Forward Looking Infrared (FLIR) imagery causes eye fatigue after 1 to 5 hours of night operations, often resulting in headaches. Pilots have reported being physically and mentally exhausted after prolonged night missions (Hale, 1989). Many pilots deal with this binocular rivalry by closing or covering their unused eye. This is a convenient but less than optimal solution. In the Objective Force Warrior System (OFW), dismounted soldiers will be wearing the HMD for an even longer period of time

due to the nature of the infantry mission. Because the vergence and accommodation reflexes are coupled, the unused eye rotates either in response to any accommodative stimulus from the open eye, or to an equilibrium position when such a stimulus is absent. The equilibrium position is normally more convergent, increasing the accommodation level of the open eye (i.e., bringing the point of focus nearer). The resulting accommodation, in many cases, is inaccurate and blurred symbology in the display (Moffitt, 1989).

A related effect is termed accommodation micropsia. When the eye is focused on an object in the foreground, objects beyond the point of focus appear smaller (or farther away) than they actually are. This effect can be demonstrated by closing one eye while focusing on one's thumb at arm's length. While maintaining focus on the thumb, draw it in towards the eye and note the apparent change in dimension of objects fixed in the background. This misperception can degrade the ability to judge distance and rate of closure (Wells, 1992).

Although day use is not as demanding as night use, experience seems to indicate that the characteristics of monocular HMDs precipitate increased user workload, stress, fatigue, and distraction. This is especially true when operating under tactical conditions (Hale, 1989).

b. Dual Ocular HMDs

Dual ocular displays present images to both eyes and are further classified into two categories: biocular and binocular. In binocular displays, an image from a single source is relayed to both eyes. A single optical path or two separate sets of optics may be employed to relay the image to the eyes. Binocular displays have separate image sources and optics for each eye. They possess higher system redundancy at the cost of higher weight. Image brightness is greater because the luminance output of the image source is not divided by the optics. Thus these displays more closely resemble the human visual system (Wells, 1992). Both types of dual ocular displays can develop problems due to optical misalignment. However, they afford up to 40%

improvement in contrast threshold over monocular systems since two eyes are better at discerning low contrast targets (Lohman, 1989).

Several major corporations are developing dual ocular HMDs for use in military aircraft and dismounted applications including CAE Electronics, GEC Avionics, Kaiser Electro-Optics, Hamilton Standard, Honeywell, and Hughes Aircraft Company. Because of the deficiencies already noted in monocular displays, the emphasis is and probably will continue to be on dual ocular systems.

Binocular viewing conditions possess several superior qualities:

- Improved visual detection at threshold values, including absolute light detection and contrast sensitivity
- Improved visual acuity
- Improved form recognition
- Improved reaction time to onset of light flashes and bar patterns (Boff, 1988).

General schematic diagram of dual ocular systems in Figure 3.

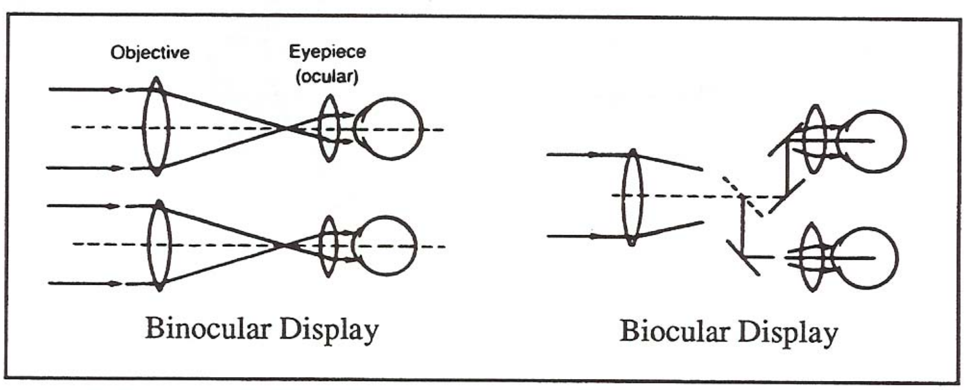

Figure 3. Dual Ocular Configurations

c. Auditory HMDs

Auditory cues play a crucial role in everyday life. Auditory cues increase awareness of surroundings, cue visual attention, and convey a variety

of complex information without taxing the visual system (Shilling, 1998). Auditory perception, especially localization, is a complex phenomenon affected by physiology, expectation, and even visual interface. Auditory processing and auditory cues in a system using helmet-mounted display (HMDs) are particularly important and should be given close attention during the design phase.

The brain automatically determines the spatial positioning of signals calculating the arrival time and intensity difference between the two ears. Headset spatialization requires special signal processing and filtering, head-related transfer filtering (HRTF) to produce the illusion that sounds are emanating from natural external locations in (3-D) acoustic space (Vause, Abouchacra, Letowski, Resta, 2001). This perception of externalized sound prevents overloading visual channels and improves situational awareness in a HMD environment.

It has also been shown that latency of saccadic eye movements toward a target is reduced when the visual target is aligned with an auditory cue (Frens, Opstal & Willigen, 1995). In this manner, a properly designed auditory interface may be used to “enhance” the field of view (FOV) for a HMD by cueing the user to locations outside the limited FOV of the HMD. The omni-directional characteristic of acoustic signals is extremely useful in inherently spatial tasks, particular when visual cues are limited and workload is high (Begault & Wenzel, 1992). Response time to visual target association with localized auditory cues has been shown to drop dramatically (Perrott, Saberi, Brown & Strybel, 1991). Appropriate care must be taken to properly design the auditory interface, as auditory location has been shown to affect perceived visual target location when the visual target is presented on a non-textured background (Radeau & Bertelson, 1976). In the absence of basic auditory cues, situational awareness can be severely degraded.

C. HUMAN PERFORMANCE

A soldier’s ability to process large volumes of information and work in a multi-task environment are critical issues to consider when providing a collaborative common operating picture to commanders on future battlefields. The term “cognitive readiness” has been defined as a measure of a system’s effects on the warfighter’s capability to perform mental functions contributing to optimal performance in a combat environment (Fatkin, McNinch, & Blackwell, 1999). New technologies are currently being developed for the military to increase cognitive readiness and the survivability and lethality of soldiers. Wearable computers, sensors, and tactile technology are components of the Army’s Land Warrior and Objective Force Warrior systems and will be used to provide tactical information to the soldier via a helmet-or wrist-mounted display. Many of these technologies require soldiers to use cognitive resources to receive and process information and make decisions. As a result, concerns have been raised about how HMDs will affect the dismounted soldiers’ capability to perform the cognitive functions necessary in a combat situation. These combat situations may include high levels of stress and physical exertion leading to fatigue, which may impinge upon the soldier’s ability to process information.

There are several competing models for how information is processed by humans. For example, Kahneman (1973) proposed that individuals possess a fixed amount of attentional capacity that can be allotted to process incoming information. Figure 4 is a schematic diagram of Kahnman’s theory on attention.

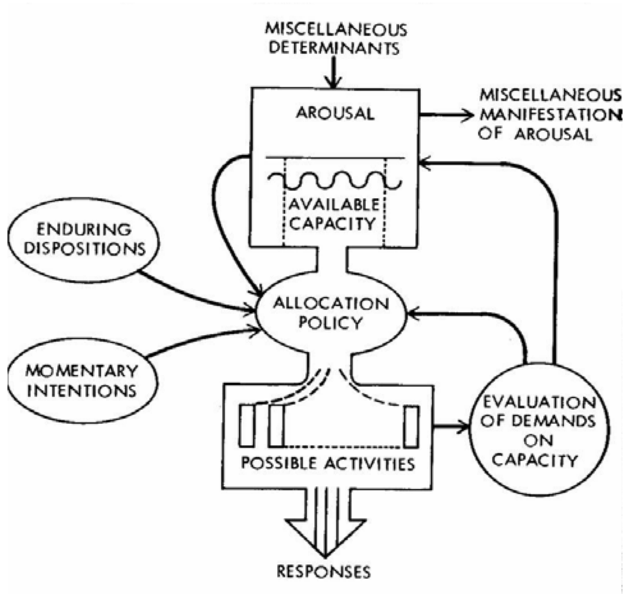

Figure 4. Unitary Resource Model of Attention (Kahneman, 1973)

Certain types of information processing such as spatial memory, time, and frequency of occurrence happen automatically, whereas other types such as imagery, rehearsal, and mnemonic techniques require deliberate allocation of attention. There is increasing concern that the use of HMDs will severely tax the soldier’s cognitive resources resulting in overload, increased errors and an increased rate of fatigue. Wickens (1984) hypothesized that human attentional capacity should be conceived as multiple resource pools, with dual-task interference being greatest when task compete for similar processing resources and least (or non-existent) when task draw from different resource pools. Wickens illustrated in theory what is known as the Multiple-resource model as shown in Figure 5.

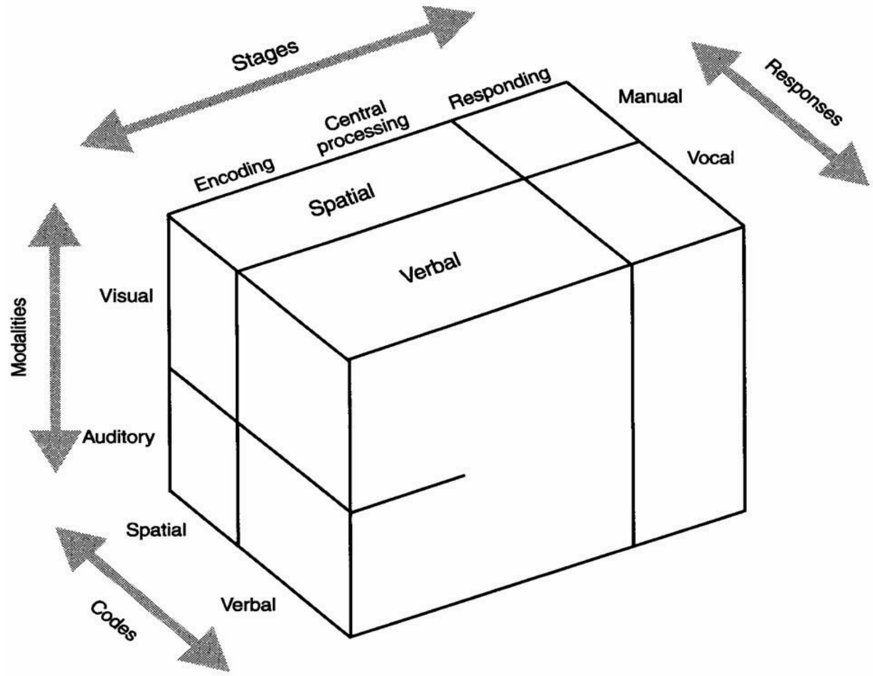

Figure 5. Multiple-resource Model of Attention (Wickens, 1984)

1. Situational Awareness

Situational awareness in a chaotic combat environment has proven to be a significant combat multiplier in leadership decision making and in many cases critical in the overall outcome of the event. Hancock and Desmond (2001) state that situational awareness relates to that dynamic and transient state of the mental model produced by an ongoing process of information gathering and interpretation during the performance of some job of work. An operator's mental model directly shapes the operator's action and determines the potential to perform in accordance with system demands (Hancock & Desmond, 2001). Situational awareness provides the primary basis for subsequent decision making and performance in the operation of complex, dynamic systems. At its lowest level the operator needs to perceive relevant information in the environment, system, self, etc. Next, the operator must integrate the data in conjunction with task goals. At its highest level, the operator can predict future events and system states based on this understanding (Endsley, 1995).

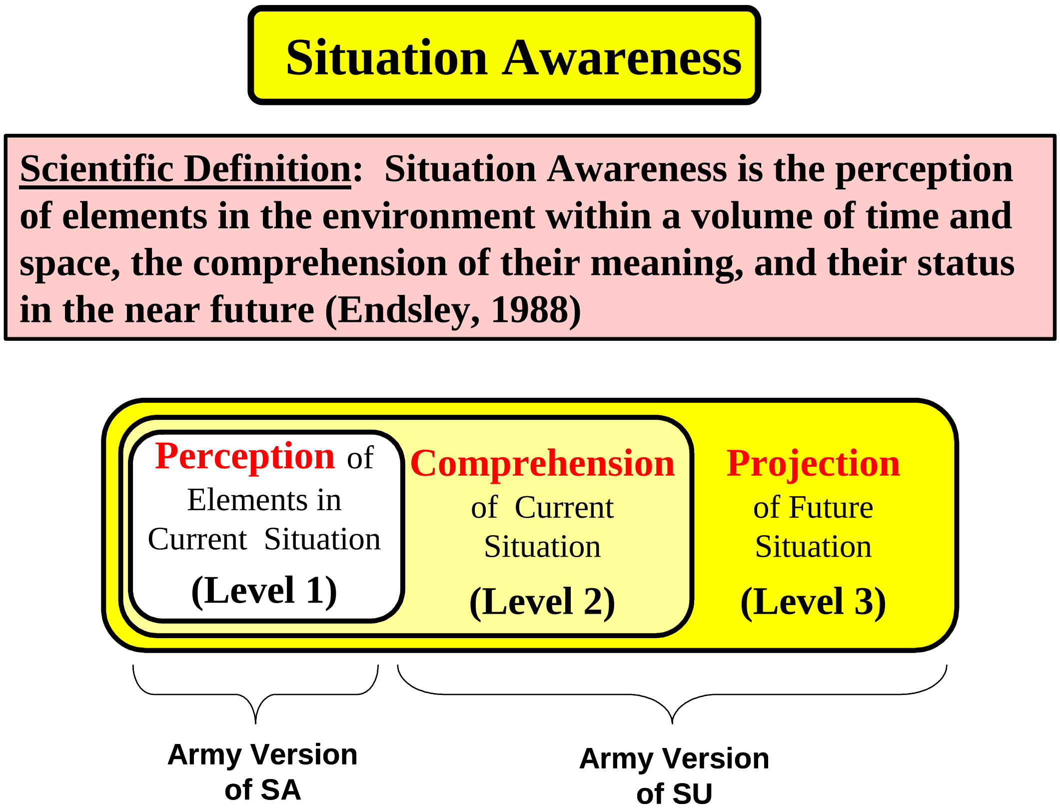

Figure 6. Situation Awareness Model (Endsley, 1988)

SA requires an operator to “quickly detect, integrate and interpret data gathered from the environment. In real-world conditions, situational awareness is hampered by two factors: data spread throughout the visual field and data that is noisy (Green, Odom & Yates, 1995). Understanding how data flow through the system, where the data may have been blocked, and how lenses may be skewed is vital to knowing how to redesign systems and develop appropriate training (Miller & Shattuck, 2004). The dynamic model of situated cognition illustrates the process of how data flows through technological systems and then interrupted by the human.

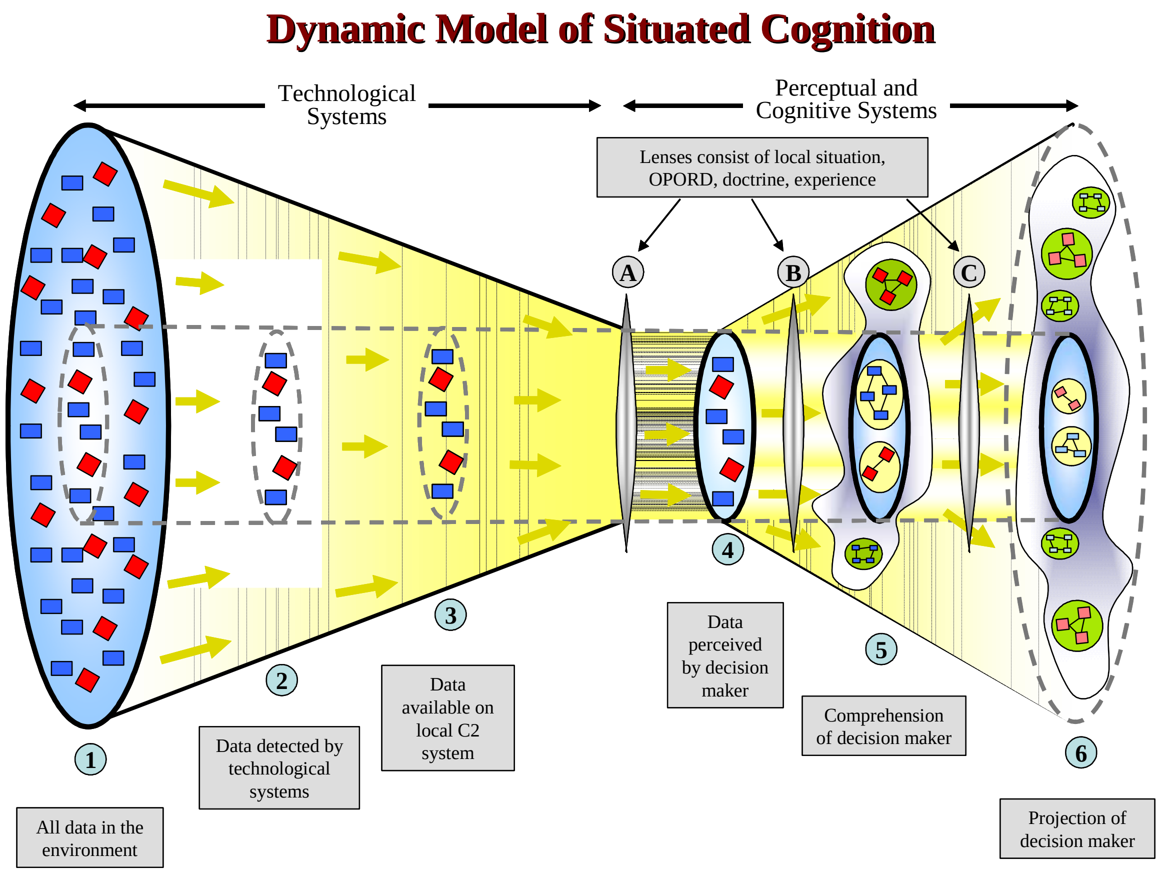

Figure 7. Dynamic Model of Situated Cognition (Miller and Shattuck, 2004)

One of the greatest challenges facing the operators and technology providers is to match our increasing capability to gather, process, and display situational awareness information with a corresponding increase in our ability to use that information (Marsh, 2000). With respect to situational awareness, a major concern for HMD technology is information overload. Increased availability of information about the situation may also be counterproductive with respect to time critical decision making. When decision makers expect information to be sparse, they tend to rely on judgment and experience to fill the voids. When information is massive and confusing, decision makers may often delay taking action until additional information can be gathered to fill voids or resolve ambiguities. They may reorient their decision making process from judgment based on experience to reliance on detailed analysis based on hard data. The

result can be “analysis paralysis,” leading to a delay of the decision until it is too late (Marsh, 2000). Designers can help avoid these pitfalls by using properly designed technology coupled with well-trained operators which will result in optimal human-system performance (Miller & Shattuck, 2004).

2. Mental Workload

Consideration of the mental workload imposed by advanced technology is important to the military acquisition community and technology designers who must provide systems that do not overburden the user with operating tasks and information clutter. Resource or capacity models of mental workload postulate a limited quantity of resources available to perform a task, and in order to perform a task, one must use some or all these resources. These models of workload address the difference between the amount of resources available within a person and the amount resources demanded by the task situation (McCloy, Derrick & Wickens, 1983). The idea of capacity stems from studies of overload of attention, in which performance deteriorates seemingly because the processing system cannot handle all the information presented to it (Mathews, Davies, Westerman & Stammers, 2000). O’Donnell and Eggemeier (1986) discuss how mental workload considers the attentional demands experienced during the performance of cognitive task. Workload also refers to people’s experience of cognitive task performance as effortful or fatiguing, which may index task demands and attentional overload (Mulder, 1986). Measures of workload can be classified into four categories: primary task measures, secondary task measures, physiological measures, and subjective measures. In this thesis, data were collected in three of these areas.

3. Human Sleep and Fatigue

Sleep is nature’s process of resting the body although brain activity continues throughout the rest period. Sleep is essential to maintaining alertness and performance levels (Hadely, 2000). Most researchers have agreed that 7 to 9 hours of sleep is required in a 24 hour period to sustain optimal performance

(Hadely, 2000). Scientific findings have clearly established that sleep is a complex active physiological state that is vital to human survival. Sleep is composed of two distinct phases: nonrapid eye movement (NREM) and rapid eye movement (REM) sleep (Van Dongen & Dinges, 1994). NREM sleep is divided into four stages, with the deepest sleep occurring during stages three and four in first third of the night. REM sleep is associated with an extremely active brain that is frequently dreaming with bursts of rapid eye movement (Bugge, Opstad & Magnus,1979). NREM and REM sleep occurs in a repetitive 90 minute cycle, with about 60 minutes of NREM sleep followed by 30 minutes of REM sleep (LeClair, 2001). Both wakefulness and sleep are modulated by an endogenous regulated system, the biological clock, located in the suprachiasmatic nuclei of the hypothalamus (Van Dongen & Dinges, 1994). The biological clock modulates our hour-to-hour waking behavior, as reflected in fatigue, alertness, and performance, generating circadian rhythmicity in almost all neurobehavioral variables (Van Dongen & Dinges, 1994). Scientific studies have revealed that based upon circadian factors there are two periods of maximal sleepiness during a normal 24-hour day. One occurs at night roughly between 0300 and 0500, with many physiological and performance functions demonstrating reduced levels from 0000 to 0600. The other occurs midday roughly between 1500 and 1700 (LeClair, 2001). Disruption of one’s circadian rhythm to accommodate adjustments in unconventional working hours has been associated with a dramatic drop in performance.

In well-rested subjects, circadian oscillations in body temperature are associated with a 10% variation in performance over the course of 24 hours, with more pronounced reduction of performance in the early morning hours. With increasing sleep deprivation, the same oscillations in body temperature are associated with 20-40% variation in performance, with a peak in the early afternoon and a trough in the early morning (Bugge et al, 1979).

Fatigue, as addressed in the human performance literature, refers to deterioration in human performance, arising as a consequence of several potential factors, including sleepiness (Maher & McPhee, 1994). Sleep total loss

is a common cause of fatigue and can be acute or cumulative. In an acute situation, sleep loss can occur either totally or as a partial loss. Total loss involves a completely missed sleep opportunity and continuous wakefulness for 24 hours or longer. Partial sleep loss occurs when sleep is obtained within 24-hour period but in an amount that is reduced from the physiologically required amount (LeClair, 2001). Over time, sleep loss accumulates resulting in sleep debt. Both cumulative and acute sleep loss have been proven to have a significant impact on overall performance (Van Dongen & Dinges, 1994). Research conducted by McCarthy and Waters suggests that a performance in a cognitively demanding task is significantly reduced when subjects miss sleep. They also conclude that after 36 hours of sleep loss, subjects were slower to attend to relevant environmental stimuli (McCarthy & Waters, 1997).

Morris and Miller (1996) in a partial sleep loss study reported that performance, as measured by error rate, significantly deteriorated over the first 3.5 hours of a 4 hour simulator flight in 10 experienced pilots. The pilot averaged only 2.4 hours sleep during the previous night. Pre and post-flight scores of subjective fatigue, workload and sleepiness increased; although, only the first two of these measures reached statistical significance (Morris & Miller, 1996). On the day after the simulated flight, subjects reported higher than normal levels of fatigue despite having an extended period of recovery sleep. This result supports the theory of Dinges (1997) suggesting that at least 2 nights of recovery sleep are required before a complete recovery is achieved. Figure 8 illustrates a one week sleep deprivation study conducted by WRAIR concluded subjects where still not totally recovered after 3 days (Belenky, Wesensten, Thorne, Thomas, Sing, Redmond, Russo & Balkin, 2003).

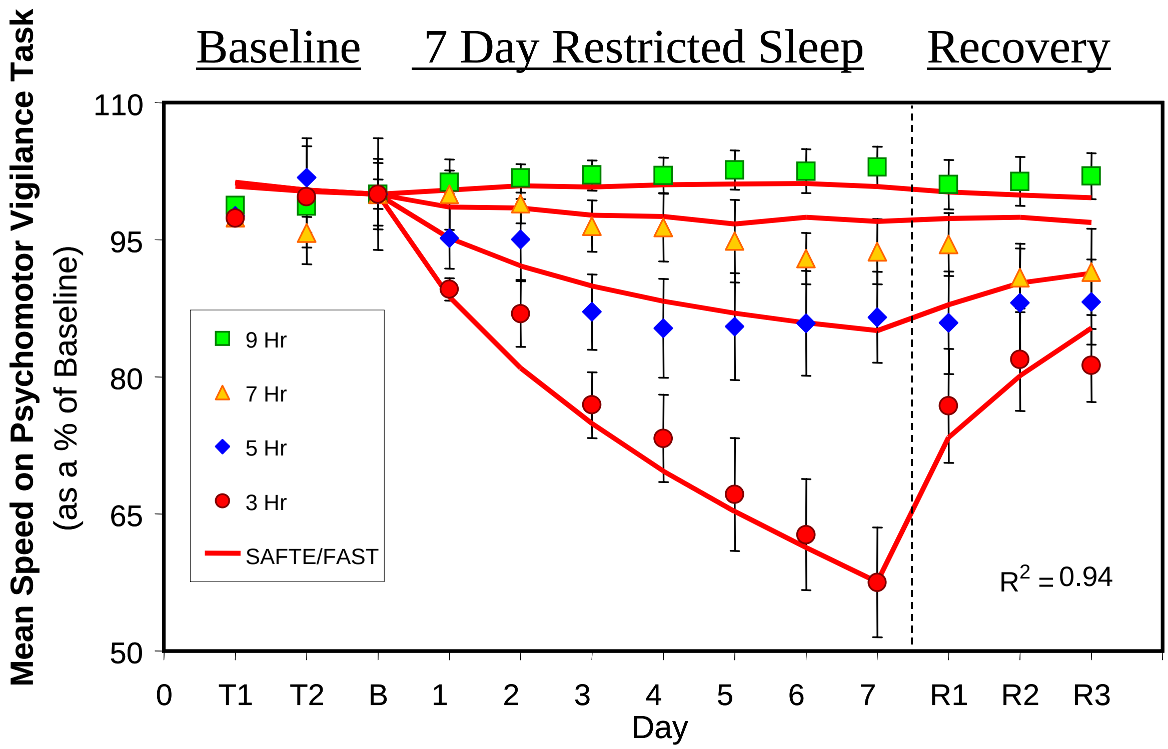

Figure 8. WRAIR Restricted Sleep Study: PVT Adaptation to Chronic Sleep Restriction (Belenky et al, 2003)

Fatigue due to continuous sleep deprivation has a significant impact on speed (information processing) and overall throughput; although, it may not significantly impact accuracy (Hadley, 2000). Additional studies have identified a number of symptoms that indicate the presence of fatigue, including: increased anxiety, decreased short term memory, slower reaction times, decreased work efficiency, reduced motivational drive, decreased vigilance, increased variability in work performance, increased errors of omission which decrease to commission when time pressure is added to the task, and increased lapses in both number and duration with increasing fatigue (Mohler, 1996; Dinges, 1995).

Throughout time, warriors have looked to leverage weapon systems and technology to dominate the opposing force. With the evolution of computers, microprocessors, satellite and wireless communication, information dominance is the weapon to leverage on the future battlefield. The proper design of the helmet

mounted display system will provide the connectivity of the future soldier into the seamless netted battlespace; however, it is critical that human-system interface considerations are addressed to minimize performance degradation.

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III. METHOD

A. SUBJECTS

Performance, stress, and workload data were collected from twelve (12) Marine Corps personnel. The average sample age was 26.6 with a maximum age of 35 years. The military specialties of these Marines were 0311 which is an equivalent of the Army's Military Occupational Specialty (MOS) 11B dismounted infantry soldier. All participants met visual acuity requirements of 20/20 in one eye and at least 20/30 in the other eye, corrected or uncorrected. They were required to pass visual tests of color and stereopsis. The participants were administered an audiogram and possessed hearing within thresholds acceptable to the U.S. Army. The military volunteers were briefed on the purpose of the study, the procedures to be followed, and the risks involved. All who consented to participate signed a Volunteer Affidavit Agreement (see Appendix A).

B. EQUIPMENT AND TESTS FOR COLLECTION OF PERFORMANCE DATA

Digitally-Aided Soldier for Human Engineering Research (DASHER II) was used to generate the visual and 3-D auditory displays and record the participants' performance. The data were downloaded at the end of each land navigation course run. The data included the calculation of the participant's distance and orientation, as measured with respect to the designated path and waypoints to which he must travel. It also calculated the secondary task of correct identification (cueing task) of friendly and enemy units while navigating the course. Participant's personal data, stress levels, subjective workload scores, and subjective ratings of sleepiness were collected and compiled in a database using Minitab 14.1. These scales and ratings included: the Multiple Affect Adjective Check List-Revised (MAACL-R), the Subjective Stress Scale (SUBJ), the Specific Rating of Events Scale (SRE), the NASA-Task Load Index (NASA-TLX) and the Stanford Sleepiness Scale (SSS).

1. Helmet Mounted Device

The HMD used in this research was part of a system developed by Rockwell International called the Trekker™ (see Figure 4). The headset consists of an occluding, monocular display developed by Kopin. The display was a monochrome active matrix liquid crystal display (AMLCD) with 640H X 480V lines. Focus and brightness-controls were integrated into the headset. The display slides left or right along the top of the unit to accommodate the desired viewing eye. The monocle assembly rotates on its arm and can be manipulated vertically to provide adjustment for eye relief (fore-aft) and display stowage. In both display modes, the participant was required to maintain the display in this position while navigating. The weight of the HMD is approximately 0.45 kilograms (1.0 pound).

The 3-D Auditory HMD used in this research consisted of two small speakers that were installed in the PASGT helmet in both display conditions. These speakers were developed by Electro Voice (Model 993) and are currently used in the integrated headgear assembly subsystem (IHAS) which is a component of the Land Warrior system. In the 3-D auditory mode, these speakers presented distance information in verbal messages spatially oriented to provide information on direction. In both modes, these speakers presented auditory alerts related to equipment malfunctions and increases in the estimated position error (EPE) of the GPS. All auditory messages were presented at a level that is comfortable but at the same time intelligible, and within signal design guidelines (Patterson, 1982). Volume was adjusted to a comfortable level for each participant during training. All sound levels were kept within allowable limits set forth by U.S. Army regulations (U.S. Army Pamphlet 40-501 [U.S. Army,1991] requirements).

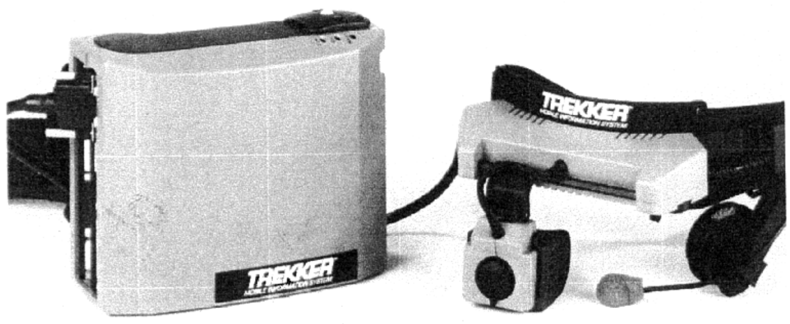

Figure 9. The Trekker™ head-mounted display.

2. Data Display and Capture

The DASHER II system was designed as a prototype system for the Land Warrior Concept. The system integrated all the technologies to be used in the ensemble to provide collaborated situational awareness of the battlefield. The DASHER system is a small Pentium computer, Global Positioning System (GPS) receiver. This equipment, along with the HMD, was integrated by Sytronic, Inc. of Dayton, Ohio. The system was stored and carried in an Army Lightweight Carrying Equipment (ALICE) backpack. During the task, the computer calculated the participant's location and orientation with respect to the designated path and waypoint to which he must travel. In visual mode, distance and orientation information was presented on the HMD in text and graphical form. In the 3-D auditory mode, distance information was provided in verbal messages presented through two speakers installed in the PASGT helmet. These verbal messages appeared to emanate from the direction that the participant must travel to regain path center. These sound files, or verbal messages, were recorded using the Knowles Electronic Mannequin for Accoustic Research (KEMAR). KEMAR was sequentially turned 5 degrees in an arc spanning 0 – 90 azimuth in one direction and then inverted for the other direction.

3. Multiple Affect Adjective Check List- Revised (MAACL-R)

The original version of the Multiple Affect Adjective Check List – Revised (MAACL-R) was published more than three decades ago (Zuckerman & Lubin, 1965). The MAACL-R has become a popular instrument for the measurement of

affects or moods as States or Traits. The 66 scorable adjective check list format allows for quick administration of the test and the respondents are not forced to compare items or rate from a scale. The respondent has the option to select as many or as few adjective as desired. The MAACL-R measures affect on three levels: 1) the factored domains; anxiety, depression, hostility, positive affects, and sensation seeking; 2) higher order affects; dysphoria = sum of anxiety, plus depression, plus hostility, and well being = positive affects plus sensation seeking, and; 3) the 12 components or facets of the domains resulting from principle components analysis (Zuckerman & Lubin, 1999). The state form of the MAACL-R is generally used to document short term mood or mood changes (i.e., how you feel at this moment). The trait form of the MAACL-R has shown good discriminative, criterion, and predictive validity (how do you generally feel). The MAACL-R has proven to have clinical application for diagnosis of affective disorders.

4. Subjective Stress Scale

In order to obtain a statistically manipulable measure of a subject's affective reaction under field experimental conditions, a scale was constructed based on the Thurstone scaling technique commonly applied to attitudinal measurement. The scale detected significant affective changes in those situations which were judged stressful. The participants are instructed to select one word from a list of 15 adjectives that describes how they feel right now or how they felt during a specific time period or event (Kerle & Bialek, 1958). The ease in administering the subjective stress scale in a field environment and the simplicity of extracting valuable stress data from the subject provides significant insight when compared with other stress measurement tools.

5. Stanford Sleepiness Scale

The Stanford Sleepiness Scale (SSS) is a quick way to assess how alert you are feeling. Most people have two peak times of alertness daily. During daylight hours, alertness wanes to its lowest point during mid-afternoon and then begins to build again. After peaking in the early evening, alertness again falls off and reaches its lowest point in the wee hours of the morning. The SSS uses a

defined scale ranging from a score of 1 to 7 to rate sleepiness level at a specific time during the study (see Table 1). For example, a subject gives a rating above three when they should be feeling alert, this is an indication that the subject may have a serious sleep debt and need more sleep.

Degree of Sleepiness	Scale Rating
Feeling active, vital, alert, or wide awake	1
Functioning at high level buts not a peak; able to concentrate	2
Awake, but relaxed; responsive but not full alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleep, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7
Asleep	X

Table 1. Stanford Sleepiness Scale

6. NASA-TLX

The NASA-TLX is a subjective workload assessment tool. NASA-TLX allows users to perform subjective workload assessments on operator(s) working with various human-machine systems. NASA-TLX is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales. These subscales include Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort and Frustration. It can be used to assess workload in various human-machine environments such as aircraft cockpits; command, control, and communication (C3) workstations; supervisory and process control environments; simulations and laboratory tests.

The NASA-TLX used in this study is a fully automated version of its predecessor pencil and paper version. Data collection may be performed through the keyboard or mouse. The use of source-of-load weighting is optional, but necessary to produce a weighted workload score. Participants were instructed to take the NASA-TLX to measure their perceived mental workload during that period of time.

7. Specific Rating of Events Scale

The SRE (Fatkin, King & Hudgens, 1990) is a measure designed for the ARL stress program in which the participants rate on a scale of 0 for “not at all stressful” to 100 for “most stress possible”. The participants were instructed to rate how stressed they feel right now or how stressful an event or time period was to them.

8. Environment Symptoms Questionnaire

The ESQ-R (Sampson & Kobrick, 1980) is used to obtain information about the incidence and severity of symptoms associated with physical stresses frequently encountered by military personnel. Using a 0 to 5 response scale, information about the subjective symptom state of the soldiers is provided by the individual item scores or by the mean scores of separate symptom categories. The symptom categories include general physical distress, fatigue, temperature sensitivity, and wellness. Responses are made relative to specified time periods in four hour increments.

C. PROCEDURES

The military volunteers were briefed on the purpose of the study, the procedures to be followed and the risks involved. All who consented to participate were required to sign a Volunteer Affidavit Agreement (see Appendix A). A visual acuity test at far and near distances was administered to ensure 20/20 vision in one eye and at least 20/30 in the other eye, corrected or uncorrected. The participants were also required to pass tests of color and stereo vision. An audiogram was administered to measure the participants’ hearing threshold levels. The participants also completed a General Information

Questionnaire (see Appendix G), the Situational Self-Efficacy (SSE) scale (see Appendix I), and Life Events Form I (see Appendix H).

Prior to training, stress perception and cognitive performance measures were administered to familiarize the soldier with the procedures to be followed in the collection of these data during the test period and to obtain baseline measures. The stress perception measures included the Multiple Affect Adjective Check List-Revised (MAACL-R) (see Appendix B), the Subjective Stress Scale (SUBJ) (see Appendix C), and the Specific Ratings of Events Scale (SRE) described in Appendix D, and the Stanford Sleepiness Scale (SSS) described in Appendix E. Cognitive performance was measured using SYNWIN .

During this period, the participants also received instruction in the assessment of their workload experience in accordance with the prescribed procedures of the National Aeronautics and Space Administration-Task Load Index (NASA-TLX). The NASA-TLX uses rating scales to assess mental, physical, and temporal demands, performance, effort, and frustration. In this technique, a weighting is obtained for each of the six workload factors based on the subject's responses to pair-wise comparisons among these factors. In these comparisons, the six factors are presented in 15 possible pairs and, for each pair, the subject is asked to circle the factor that they perceived contributed more to his/her workload experience. The subject then completed rating scales that provided a measure of the magnitude of the workload for each factor. Those factors perceived by the subject to be most important in his or her workload experience were given more weight in computing the overall workload score. Definitions of each of the six workload factors assessed, the pair-wise comparison, and rating scales are provided in Appendix F.

1. Training

The 12 participants were divided into two groups of six individuals and were trained and tested over a one week period. Prescreening was performed and baseline measures obtained on the first day. Duration of training was two days: one day of training in each of the two display modalities. On the first day of

training, three of the six participants were trained on the tasks they performed during testing in the visual display condition, and the remaining three participants were trained to perform the same tasks in the 3-D auditory mode. On the second day of training, this procedure was reversed and the participants received training in the remaining display mode.

In both conditions, training included classroom and field instruction during which the participants were trained to asymptote in the performance of the primary (navigation) and secondary (enemy detection) tasks. During the training period, the participants completed runs on training paths with all tasks performed during the actual testing period. Each test participant was accompanied on the training path by a "lane walker." A lane walker also accompanied the participant throughout testing in each display condition. The lane walker was equipped with a handheld GPS receiver. Lane walker functions include equipment troubleshooting and administration of the stress perception measures. Two sets of lane walkers (i.e., four lane walkers) were assigned to each 12-hour shift on each day of the testing period to avoid lane walker fatigue.

2. Testing

Prior to the test period, stress perception (MAACL-R, SUBJ, SRE) and cognitive performance measures (SYNWIN) were administered to the study participants. The participants also completed the Environmental Symptoms Questionnaire (ESQ) and the Stanford Sleepiness Scale (see Appendix E). The schedule for administration of these measures and the NASA-TLX during and after the testing period was as follows:

(1) Pre-Test: MAACL-R, SUBJ, SRE, SLEEP, and ESQ

(2) After EACH run in EACH display condition (i.e., every 4 hours):

MAACL-R, SUBJ, SRE, SLEEP, NASA-TLX

(3) Every 12 hours: ESQ

(4) Post-Test (end of 48-hour test period): Same as (2) plus ESQ

For each group of six participants, the 48-hour test period began at 0800 hours on the morning of Day 4 (Time 0). The schedule followed during the first 24 hours of the test period is provided in Table 2. A similar schedule was followed for the last 24 hours, of the test period. During the entirety of the 48-hour test period, participants were not allowed to sleep. Investigators monitored the participants at all times, including during “rest periods” (coffee breaks), to ensure that participants remained awake and did not take naps. During the first two hours in each 4-hour time block, each of the six participants navigated a different unmarked path in one of the two display conditions. Two participants navigated at one time but on different test paths. One of the two participants navigated in the visual mode and the second participant navigated in the 3-D auditory condition. In the second 24-hour period, the participants navigated the same paths that they navigated during the first 24-hour period but in the reverse direction (i.e., at alternate starting points).

In both display conditions, the participants were required to perform a second task while navigating. A description of the primary and secondary tasks to be performed in this study, and the data to be collected for each of these tasks are included in the following section:

Navigation (Primary Task). The participant was instructed that speed and accuracy are equally important when navigating from waypoint-to-waypoint and told to maintain his position on the optimum straight-line path between these points. The participant was informed that he could obtain information on his distance and orientation with respect to the designated path or waypoints at any time by depressing the “Path” or “Waypoint” buttons on his keypad. Navigation accuracy was determined by the measures of the participant’s velocity within each leg which is computed by dividing the time to navigate each leg by the distance he traveled. Any time spent at waypoints was not included in calculations of time, nor was any time spent in diagnosing and resolving equipment problems. In each run, the frequency at which the participant depressed the “Path” and “Waypoint” buttons was recorded.

Unit Position Monitoring (Secondary Task). The participant was instructed that speed and accuracy in navigating from point to point was his primary task and critical to mission success. He was also informed that while he was navigating he must monitor his visual display for enemy and friendly units that achieve a distance of 100m from his position. He was asked to detect and identify as many of these units as possible while still maintaining his speed and accuracy in navigation. The number of units detected, time to detect, and the number of incorrect identifications was recorded.

3. Experimental Design

The study is a repeated measures design with display modality (visual and 3-D audio), day (2 24-hour periods), and session (24 two-hour sessions) as within-subject effects. The dependent variables include navigation performance (navigation time or velocity) and performance on the secondary task (number of enemy correctly detected, time to detect, and number of incorrect identifications).

The 12 sessions represent each 4-hour increment in time between presentations of the same display condition during the 48-hour test period. For each participant, there is a two-hour separation from the presentation of one display condition to the presentation of the second display condition. Staggering of display presentations is necessary due to the limitation in the number of DASHER systems and the need to expose all participants, as equally as possible, to each display condition within each 4-hour period.

The dependent variables for the psychological data include stress response levels (anxiety, depression, hostility, positive and negative affect), and subjective ratings of self-efficacy, sleepiness, fatigue, and physical symptoms. The dependent variables for cognitive performance include accuracy and number attempted of the SYNWIN components (recall, addition, visual tracking and auditory monitoring).

PRE-STUDY	BASELINE	DAY 3	TEST	TEST
Inprocessing	*Basline Testing*	*Normal Day*	*Start SUSOPS*	*Start SUSOPS*
Consent, and Briefing	for Cognitive and Psychological measures	Normal Rest and Sleep	Day 1	Day 2
Screening and test a	B1 b,d, 10 min rest, c	No Testing	Start auditory or visual test sessions	
3 Practice period for test c	B2 b,d, 10 min rest, c		S1 b,e, 10 min rest, c	S13 b,e, 10 min rest, c
	B3 b,d, 10 min rest, c		S2 b,e, 10 min rest, c	S14 b,e, 10 min rest, c
	B4 b,d, 10 min rest, c		S3 b,e, 10 min rest, c	S15 b,e, 10 min rest, c
	B5 b,d, 10 min rest, c		S4 b,e, 10 min rest, c	S16 b,e, 10 min rest, c
	B6 b,d, 10 min rest, c		S5 b,e, 10 min rest, c	S17 b,e, 10 min rest, c
	B7 b,d, 10 min rest, c		S6 b,e, 10 min rest, c	S18 b,e, 10 min rest, c
	B8 b,d, 10 min rest, c		S7 b,e, 10 min rest, c	S19 b,e, 10 min rest, c
	B9 b,d, 10 min rest, c		S8 b,e, 10 min rest, c	S20 b,e, 10 min rest, c
	B10 b,d, 10 min rest, c		S9 b,e, 10 min rest, c	S21 b,e, 10 min rest, c
	B11 b,d, 10 min rest, c		S10 b,e, 10 min rest, c	S22 b,e, 10 min rest, c
	B12 b,d, 10 min rest, c		S11 b,e, 10 min rest, c	S23 b,e, 10 min rest, c
	Normal Sleep Period		S12 b,e, 10 min rest, c	S24 b,e, 10 min rest, c

Table 2. Schedule for the administration of cognitive and psychological measures

*Testing codes
a. Life Events Form I, SSE, and GIQ
b. MAACL, SUBJ, SRE, SLEEP
c. SYNWIN d. ESQ e. NASA-TLX

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IV. ANALYSIS

This analysis focused on warfighter performance, comparing two different helmet-mounted display modes (visual and 3-D auditory) over a 48-hour period in which participants were totally sleep deprived. The study had two independent variables: HMD mode (visual vs. 3-D auditory) and total sleep deprivation (TSD) for 48 hours. Outcome or dependent variables included land navigation (primary task) and enemy detection (secondary task) performance collected during a simulated field exercise. Additional, dependent measures of subjective mental workload and stress were also examined.

The following chapter provides a descriptive and statistical analysis of HMD modality (visual and 3-D auditory) and sleep deprivation effects on subject’s performance in the primary task (navigation time) and secondary task (enemy detection), as well as subject’s perceived level of workload, and stress. Statistical analysis was conducted on the primary task (navtime) and the secondary task (enemy detection) measures, workload measures (NASA-TLX), mood data from the MAACL-R, and subjective stress questionnaire.

A. NAVIGATION TIME VS. CONDITION

Figure 10 illustrates the distribution of navigation time in the two HMD modes. Subjects operating in the 3-D auditory mode required more time to complete the course than subjects operating in the visual mode. The mean time for subjects using visual HMDs to complete the course was 13.6 minutes compared to 19.6 in the 3-D mode.

The primary task data were checked for normality. The Anderson-Darling test (A-DT) was conducted on the primary task data to verify the assumption of normality. The results of the A-DT concluded with a p-value = .005, failing to reject the null hypothesis that the data follows a normal distribution.

A two-sample t-test was conducted to determine if the navigation time was significantly different between the two HMD modes. There were significant

differences between HMD modes (t= -3.27, p = 0.001). The difference in navigation time between modes was 6 minutes, with participants taking approximately 45% longer when wearing the 3D auditory HMD as compared to the visual mode.

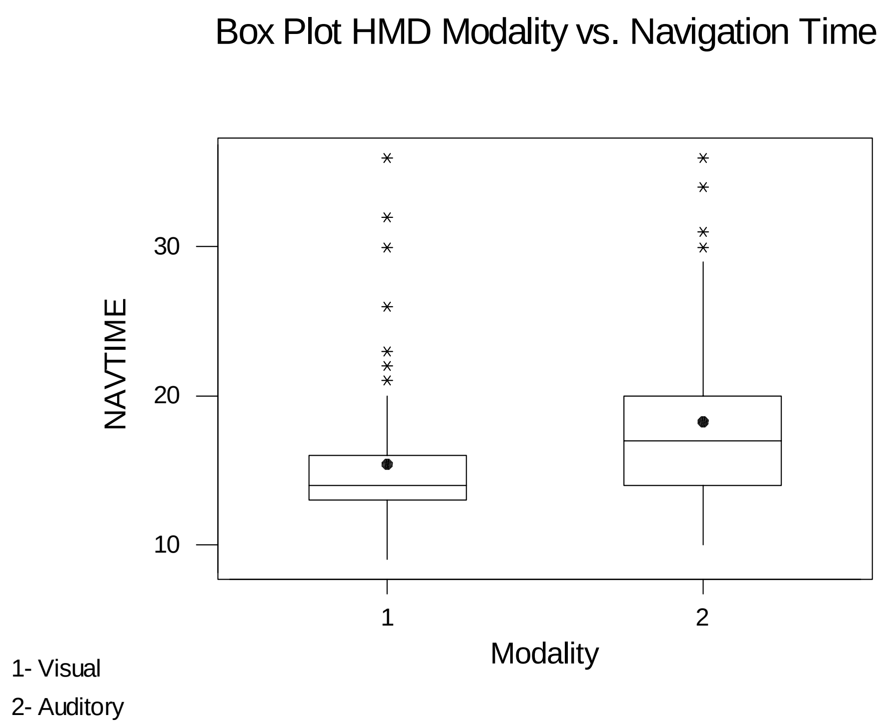

Figure 10. HMD Condition vs. Navigation Time

B. ENEMY DETECTIONS VS. CONDITION

The Anderson-Darling test (A-DT) was conducted on the secondary task data to verify the assumption of normality. The results of the A-DT concluded with a p-value = .048, failing to rejecting the null hypothesis that the data follows a normal distribution.

Soldier performance in the secondary task (number of detections) was examined to determine if it was affected by HMD mode. This comparison was accomplished using a two sample t-test. The t-test revealed no significant difference in expected enemy detections between different modalities (t = - 0.78, p= 0.434). Figure 11 shows a box plot of enemy detections by HMD modality.

Box Plot HMD Modality vs. Detections

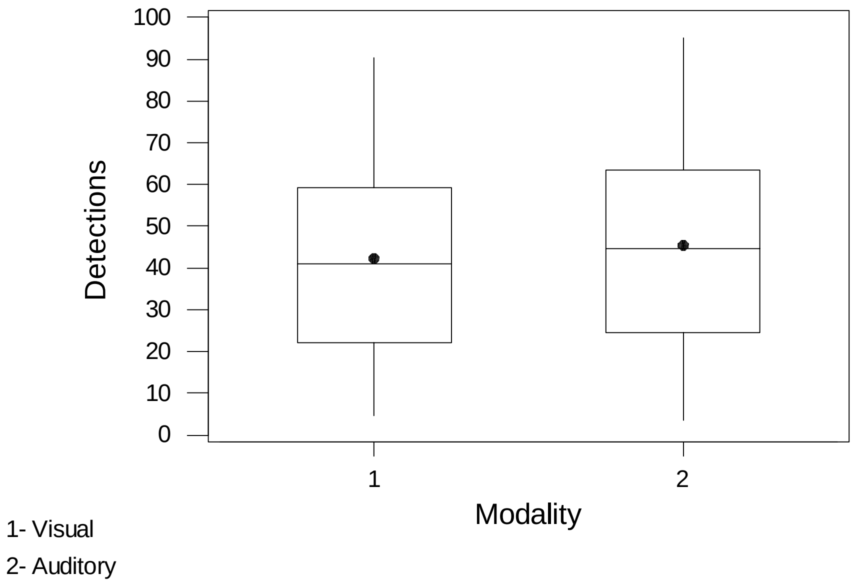

Figure 11. HMD Condition vs. Enemy Detections

C. NAVIGATION TIME WITH INCREASING LEVELS OF SLEEP DEPRIVATION

A one-way analysis of variance (ANOVA) was conducted to determine if the navigation time is significantly different over time and increasing sleep deprivation. The null hypothesis states that the mean navigation times for each of the 12 time periods are equal while the alternate hypothesis states that at least one time block is different. There were significant differences in the average navigation time for at least one time block ($F_{11,132} = 6.74$, $p = .001$). Figure 12 illustrates a 95% confidence interval for the mean time to complete an 880 meter land navigation course. Visual inspection of the data provides insight into how sleep deprivation may affect navigation performance.

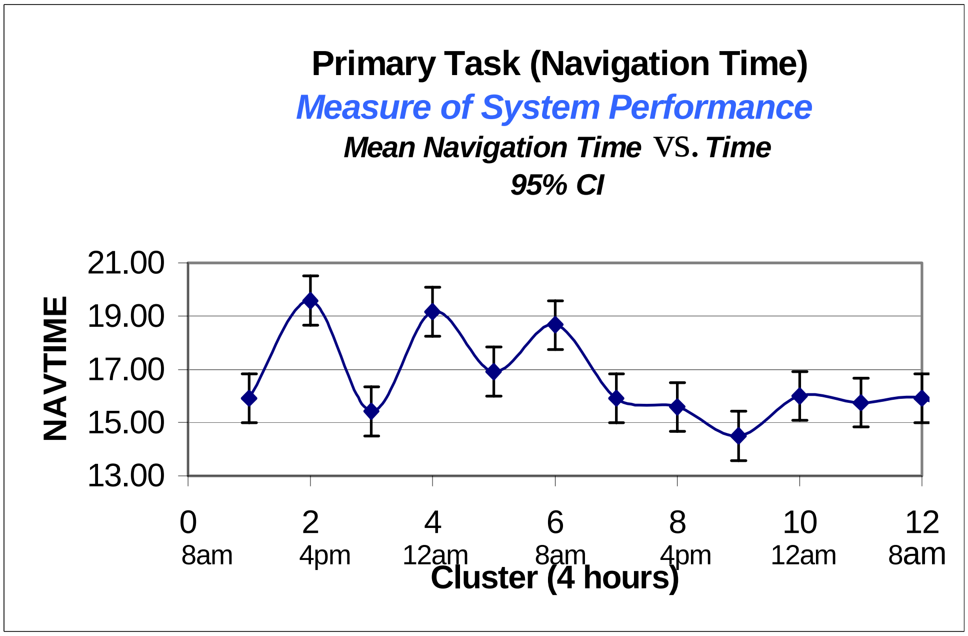

Figure 12. Navigation Performance over Time

The primary task performance varied with time and increasing sleep deprivation but declined over the course of the entire experiment. Lower values of navigation time indicate better performance. As seen in the graph above, navigation time actually decreased over the 48 hours of the experiment. The fastest navigation time was recorded at 8 pm of day 2. Navigation performance peaks and ebbs several times throughout the course of the 48 hour of sustained operation. Navigation time first increases to 19.5 minutes at approximately 4 p.m. of day 1. Then navigation time decreases again at 9 pm of day 1 to 15.5 minutes. At 12 a.m. of the first day the mean performance time increases again to 19 minutes, taking four minutes more to complete the land navigation course then at 4 p.m. of that same day. Performance again dips at 4 a.m. with navigation time increasing on average by two minutes from the peak performance of Day 1. Performance again degrades at 8 am of day 2 and peaks again at 8 pm of day 2.

Figure 13 shows a scatterplot with data points connected using a smoothed line to compare the effects of increased sleep deprivation on the primary performance task of navigation time for subjects operating in both the

visual HMD and 3-D auditory HMD. The plot breaks out the two modes and superimposes them on the same graph to compare performance characteristics and effects of sleep deprivation at specific periods. Subjects' performance in the two modes peaked at different levels of sleep deprivation. The pattern of the data would indicate that at specific periods of increased sleep deprivation, subjects' performing navigation tasks in the visual mode peaks while performance in the auditory modes at that same period is degraded.

Additionally, performance in both modes tends to oscillate in the first 20 hours of sleep deprivation; however, during later stages of testing, subject's performance in the visual mode begins to level off. Subjects' performance in the auditory modality continues to oscillate during later stages of sleep deprivation. Although there are performance effects for both modalities with increased sleep deprivation, the data indicate a pronounced drop-off after 20 hours of continuous operations when using the 3-D auditory HMD.

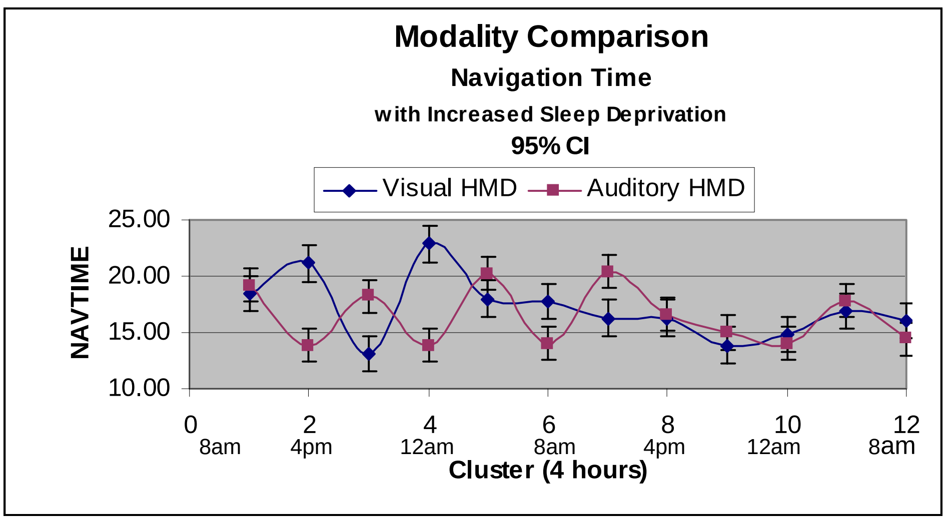

Figure 13. Modality Performance Comparison over Time

D. ENEMY DETECTIONS WITH INCREASING LEVELS OF SLEEP DEPRIVATION

A one-way analysis of variance (ANOVA) was conducted to determine if the number of enemy detections was significantly affected by sleep deprivation. The single factor used was the 4 hour time block, a proxy for cumulative sleep

deprivation. The ANOVA compares mean performance between time blocks. The null hypothesis is that the mean number of detections is the same for each time period, while the alternate hypothesis states that the mean number of detections for at least one time period is different

The ANOVA test revealed significant differences in the average number of enemy detections for at least one time period ($F_{11,132}$ =12.97, p =.0001) Figure 14 illustrates the mean number of detections over a 48 hour sustained period, providing detailed insight to the effects of sleep deprivation on secondary task performance.

Several peaks and ebbs are clearly defined during specific time clusters which parallel the oscillatory characteristic of the natural circadian rhythm. The performance of the secondary task peaks is at its highest at 8 pm of day 1 and degrades to it lowest point at 2 am of day 1. Performance again spikes at 8 am of day 2 but decreases on average 7 detections from the peak performance of day 1. At 4pm of day 2 with continuous sleep deprivation, subjects' performance degrades to it lowest point but spikes again at 12 am of day 2 with degraded performance of 9 less detections from Day 1 detection level. When subjects are sleep deprived for 40 hours, detections continuously decrease reaching a degraded performance level of 17 fewer detections from the peak detection rate on day 1. The graph indicates that as sleep deprivation increases, performance oscillates but continues to generally degrade for the entire 48 hour period.

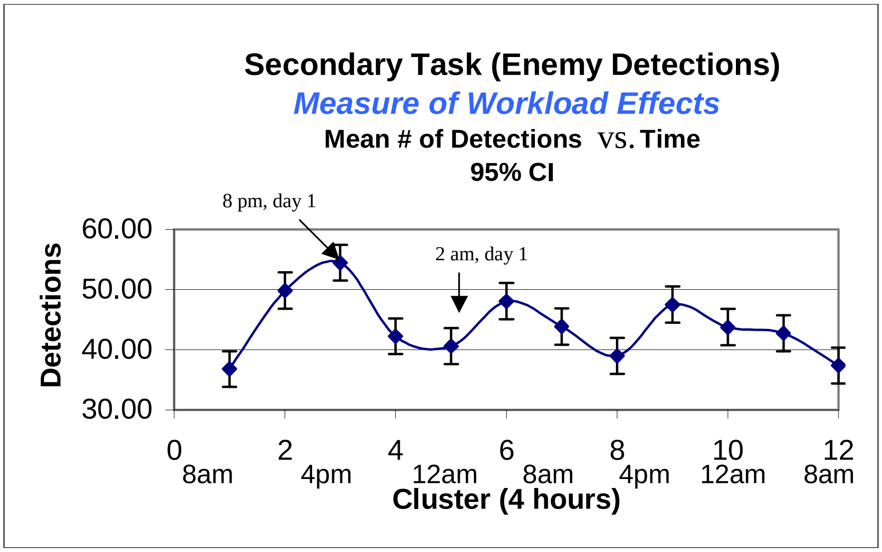

Figure 14. Secondary Performance Effects over Time

Figure 15 uses a scatterplot with data points connected using a smoothed line to compare the effects of increasing levels of sleep deprivation on enemy detections while operating in both the visual HMD and 3-D auditory HMD. This plot illustrates how performance differs between the two HMD conditions while sleep deprived and at what point performance is most degraded.

An examination of Figure 15 shows a well-defined oscillation in performance. There are noticeable differences in performance over time, indicating how sleep deprivation impacts secondary task performance conducted in the visual versus auditory modes. Somewhat less noticeable are changes in the auditory performance plot over time suggesting that sleep deprivation may have less of an effect on the secondary task in the auditory than in the visual mode.

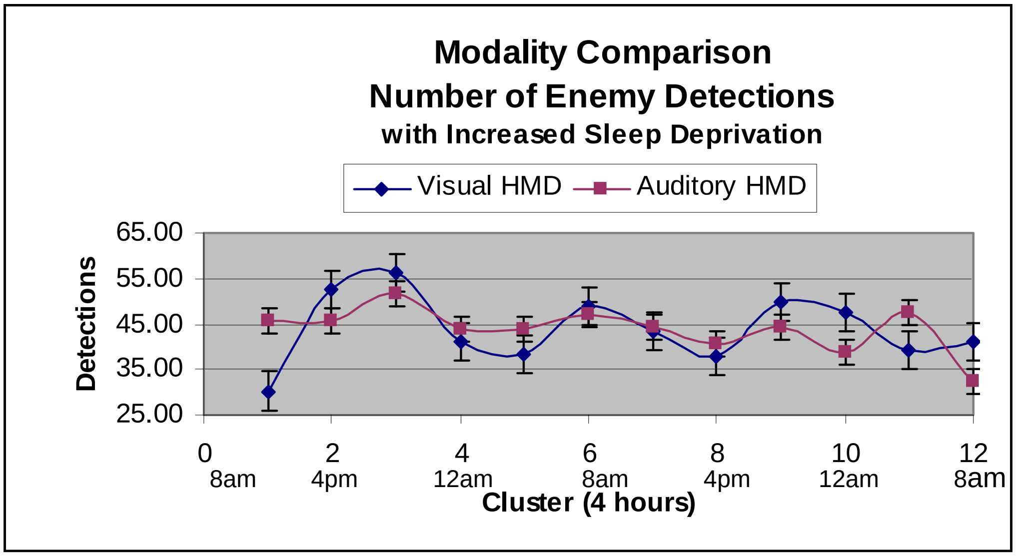

Figure 15. Performance of Two HMD Modes over Time

E. MAACL-R ANXIETY LEVELS WITH INCREASED SLEEP DEPRIVATION

Anxiety levels of subjects were examined for possible differences when operating in the 3-D auditory modality versus the visual mode. A two-sample t-test was conducted to determine if the level of anxiety was significantly different between HMD modalities. The t-test revealed no significant difference in anxiety for the two different modes ($t = -2.50$, $p = 0.191$).

The level of anxiety was then examined to determine how it was affected by increasing levels of sleep deprivation. A one-way analysis of variance (ANOVA) was conducted to determine if anxiety levels were significantly different over time. The null hypothesis was that the mean anxiety level was equal for each time period, while the alternate hypothesis states that at least one time period is different. The ANOVA test revealed no significant differences in the

anxiety levels over time clusters ($F_{11,132}$ = .69, p-value= 0.746). The experiment was unable to demonstrate increased levels of anxiety as a result of increased sleep deprivation.

F. MAACL-R HOSTILITY LEVELS WITH INCREASED SLEEP DEPRIVATION

A two-sample t-test was conducted to determine if the level of hostility was significantly different between HMD modality. The t-test revealed no significant difference in hostility for different modalities (t= -2.71, p = 0.159).

The level of hostility was then examined to determine the effect of increased sleep deprivation. A one-way analysis of variance (ANOVA) was conducted to determine if hostility levels were significantly different by time period. There was no significant difference in the expected average hostility level over time clusters ($F_{11,132}$ = .95, p-value = 0.496) at a significance level α =.01. The experiment did not find a relationship between sleep deprivation and perceived level of hostility of the test subjects.

G. MAACL-R DEPRESSION LEVEL WITH INCREASED SLEEP DEPRIVATION

A two-sample t-test was conducted to determine if the level of depression was significantly different between the two HMD modalities. The t-test revealed no significant differences in depression between modalities (t= 0.21, p = 0.830). The level of depression was then compared to determine the effects of increased sleep deprivation. A one-way analysis of variance (ANOVA) was conducted to determine if depression levels were significantly affected over time. The ANOVA test revealed no significant differences in the expect average depression level over time clusters ($F_{11,132}$ =.97,p-value= 0.465). Based on the results of this experiment, there is apparently no significant relationship between sleep deprivation and the perceived level of depression of test subjects.

H. WORKLOAD (NASA-TLX) OVER INCREASED SLEEP DEPRIVATION

A two-sample t-test was conducted to determine if the level of workload was significantly affected by HMD modality. The t-test revealed significant differences in workload for different modalities ($t = -4.39$, $p = 0.000$). On average participants in the 3-D auditory HMD (auditory workload mean=32.5, s.d.=18) experience a higher level of workload than in the visual HMD (visual workload mean=22.1, s.d=12). The level of workload was then compared to determine the effects of increased sleep deprivation. The ANOVA test revealed a significant difference in the average workload level over time ($F_{7,184} = 2.35$, $p = 0.025$). Figure 16 indicates that subjects operating in the auditory mode experience a consistently higher workload level.

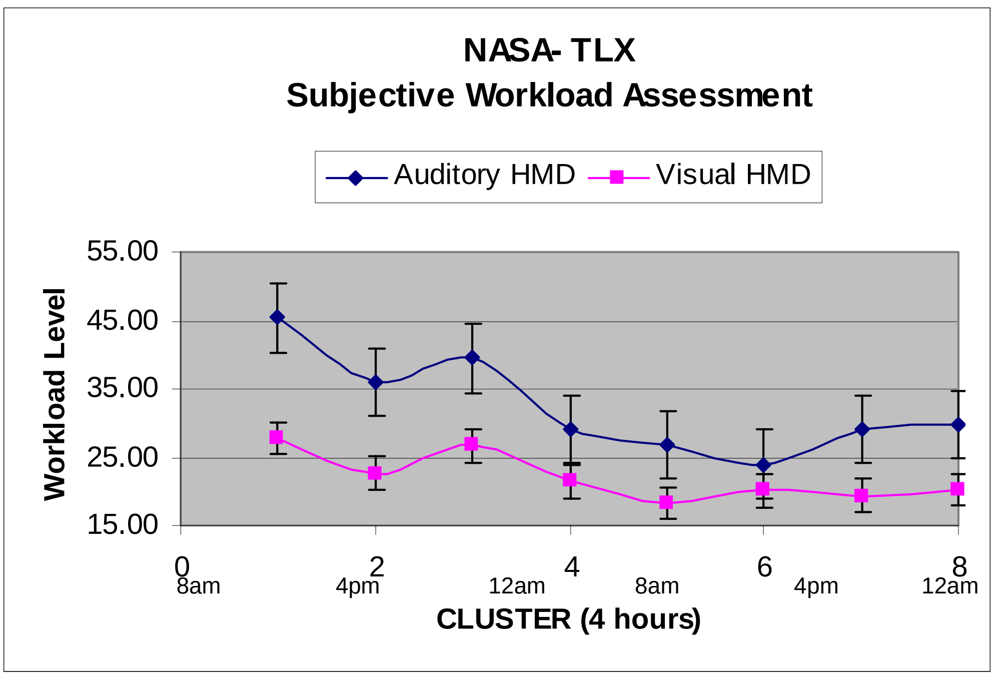

Figure 16. NASA-TLX Workload Effects over Time

I. SPECIFIC RATING OF EVENTS OVER INCREASED SLEEP DEPRIVATION

A two-sample t-test was conducted to determine if the level of stress is significantly different between HMD modalities. The t-test revealed no significant

difference in stress for different modalities (t= -2.68, p = 0.342). The level of stress was then examined to determine the effect of increased sleep deprivation. A one-way analysis of variance (ANOVA) was conducted to determine if stress levels were significantly affected by time and increasing sleep deprivation. The ANOVA test revealed no significant difference in the average stress level over time ($F_{11,132}$ =.74, p= 0.695). Figure 17 illustrates the stress levels of Marines with increased sleep deprivation.

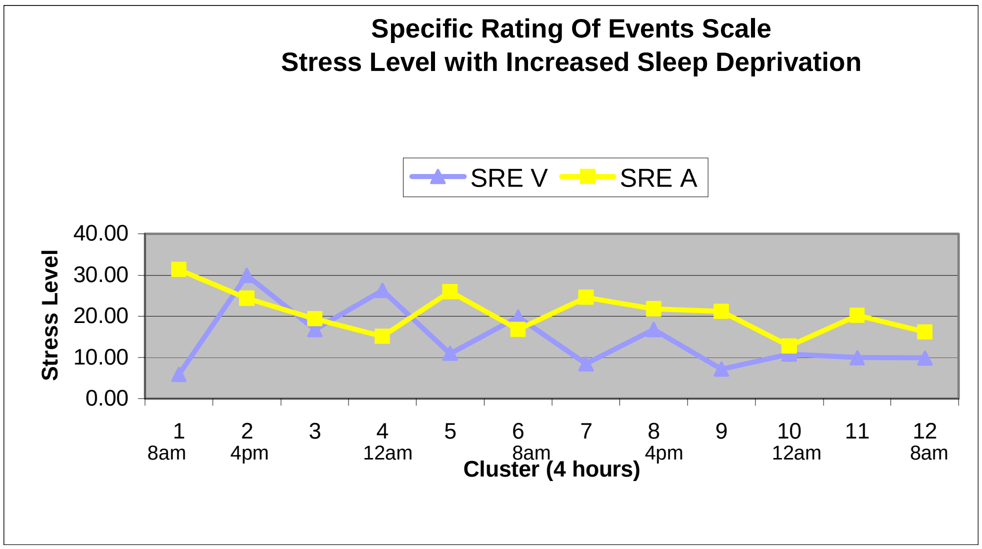

Figure 17. Stress Level Effects (SRE) over Time

While a statistically significant relationship between stress and sleep deprivation was not demonstrated in the experimental data, separating stress by modalities shows interesting results over time. Figure 17 shows a transition of stress level with respect to time and modality. Subjects' stress levels in the visual mode peak at four different times throughout sleep deprivation study. These spikes take place at 4 pm of day 1, 12 am of day 1, 8am of day 2 and 4 pm of day 2. The 3-D auditory modality tends to reflect a higher stress level during early stages of the study.

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V. DISCUSSION AND RECOMMENDATIONS

A. DISCUSSION

A primary purpose of this study was to examine the effects of sleep deprivation and circadian cycle on navigation performance, psychological stress and workload when position information for navigation is presented in two different HMD modalities. An additional purpose was to examine the effects of different types of HMD modes on soldier mental workload and stress levels.

The results indicated that sleep deprivation had a significant impact on both the primary task of land navigation and the secondary task of enemy detection in both HMD modes. Participants completed the land navigation course in less time using the visual helmet-mounted display than when using the 3-D auditory helmet-mounted display. This difference may be attributed to the fact that the human visual system is the primary system used in navigating through the environment, a natural ability that is rehearsed daily while use of the auditory system to navigate is a learned skill. This distinction was clearly reflected in the results. Although differences in the navigation time between the visual HMDs and 3-D auditory HMD were significant, the number of enemy detections between modalities was statistically insignificant.

Primary task performance closely mirrored performance changes found in scientific research into performance and circadian rhythms. Primary task performance was better during mid-morning, late afternoon, and mid-evening. Increasing sleep deprivation affected participants' performance of land navigation more in the visual mode as compared to auditory mode. Results also showed that soldiers performing both the primary and secondary task simultaneously in visual mode experienced a possible overload in information to the visual channel, i.e., when both the primary and secondary task competed for the same sensory resource (both task were visual), the secondary task of enemy detections was clearly degraded with increasing levels of sleep deprivation.

Additionally, this analysis showed differences in the patterns of performance of the primary and secondary tasks. Performance in the primary task peaks approximately two hours prior to the peak performance in the secondary task. This relationship could be explained by the concept of task shedding indicating that attentional resources were being allocated to the performance of the primary task with fewer resources left for the secondary task. At the highest levels of sleep deprivation, the effects on the primary task as compared to the secondary task showed less degradations. Participants were able to continue to perform their primary task, even under severe sleep restriction.

The results from the MACCL-R and Specific Rating of Events Scale which measures mood and stress respectively, revealed no significant difference between the two different modes. Regardless of modality, as stress increased, performance (whether number of detections or navigation time) decreased. There was a significant difference in the perceived workload level between the modalities. Participants experience significantly higher workloads in the 3-D auditory configuration as compared to the visual configuration. Workload and stress levels in both modalities were highest during the first 12 hours and begin to oscillate at different levels, although never exceeding the initial levels. This finding was strong indication that there was a learning effect occurring in the study population that was offsetting or masking the effects of fatigue. Training participants during baseline to asymptote would have addressed this problem.

The correct design of the helmet-mounted display is critical in optimizing the performance in an HMD environment. Based on the findings from this thesis, the significant difference in the performance of the land navigational task between visual and auditory modes and the substantial differences in performance attributable to sleep deprivation when operating in the visual mode are causes for concern. The possible impact of additional stress and higher workloads when operating in the 3-D auditory mode supports the need for more research to explore how best to combine auditory and visual displays in future technologies to more closely support the human in the system.

B. RECOMMENDATIONS

Four major recommendations have resulted from this study and are listed below. First, baseline performance for all participants in both visual and auditory modes is essential to any future study. Secondly, the inclusion of a fully rested control group would significantly strengthen the design of the study. Thirdly, more frequent (e.g., hourly) measurements of performance would be tremendously valuable. If implemented, time series methods could be used to model and potentially forecast performance. Finally, dedicated groups should be assigned to perform either auditory or visual modes. While study designs using within subjects effects are generally more powerful, for future studies it would be preferable to adopt a between groups design. The adoption of this type of design will eliminate the confusion of modality with sleep deprivation and enable researchers to differentiate between these two potentially confounding factors.

It is critical that system designers do not overburden the soldier by developing systems that operate contrary to the human sensory system. It is essential that the HMD for OFW is designed and functions to counterbalance the effects of channel overload in order to achieve optimal performance. Most important, military leadership must be educated on the possible negative ramifications of exposing their solders to HMDs in a sustained operational environment. If not managed properly, the use of HMDs when sleep deprived will lead to degraded performance. This degradation will ultimately undermine the advances in technology and will lessen the combat effectiveness of the military unit.

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APPENDIX A. VOLUNTEER AFFIDAVIT AGGREEMENT

VOLUNTEER AGREEMENT AFFIDAVIT

Army Research Laboratory
Human Research and Engineering Directorate
Aberdeen Proving Ground, MD

Title of Research Project:	**The Effects of Fatigue and Display Modality on Position Determination and Cognitive Workload**	**Log No.:**	
Principal Investigator:		**Phone No. (com):**	**(410) 278 - 5986**
Location of Investigation:	**Spesutie Island, EMP Range Aberdeen Proving Ground, Maryland**		

In the future battlefield, you will be provided much more information than you are provided now. Some of this information will be presented visually on a hand-held or helmet-mounted display (HMD), and some of this information will be presented auditorily. The design of these visual and auditory displays will have a major impact on your ability to understand and use this information to your advantage especially when you are tired. Your participation in this research will help in the development of new display technologies that will enhance and sustain your effectiveness.

The objective of the present field study is to measure the effects of fatigue on your ability to navigate using information presented in each of two different display conditions (i.e. visual and 3-D auditory). During this study, you will navigate a different unmarked path within an illuminated field using navigation information presented in these two display conditions. You will do this every four hours for a duration of 52 hours without sleep. The length of each path you will navigate is approximately 900 meters.

In the visual display condition, you will be provided information on your position with respect to waypoints and designated paths between these waypoints on a map of the area of operation. You will view this map on an HMD. In the 3-D audio display condition, information on your distance with respect to these waypoints and paths will be supplied in verbal (speech) messages presented through two small earphones installed in your helmet. These verbal messages will sound as though they are coming from the direction that you need to travel to reach your waypoint or path. In both the visual and the 3-D audio display conditions, you can obtain information on your position with respect to your next waypoint and the designated path at any time by depressing buttons on a keypad that you will wear on your belt.

In both the visual and 3-D audio display conditions you will wear an HMD. This HMD will provide you visual information on the distance of enemy and friendly units from your position. We will ask that you monitor this display as best you can while navigating to determine when an enemy or a friendly unit is 100 meters from your position. During the 56 hour test period we will also administer questionnaires that assess your experiences of stress, cognitive performance, sleepiness, and workload.

During the study you will carry a dummy M16 rifle. You will also carry an ALICE backpack which will hold a small computer, a GPS receiver, an electronic compass, and a 12-volt battery that powers this equipment. The backpack and equipment weigh approximately 10 kilograms (22 lbs).

The expected duration of your participation in this study is approximately 5 1/2 days. On the first day you will be provided vision and hearing tests and become familiar with the procedures to be followed during the study. Training with each of the two displays will be conducted on Day 2 and 3. The 52 hour test period will begin at 0800 hours on Day 4 after a good nights sleep and continue to 1200 hours without sleep on Day 6. You will not be allowed to sleep at any time during the 52-hour test period. Throughout this period test personnel will monitor you to make sure you stay awake. If you cannot stay awake and choose to withdraw from the study, please inform your lane walker. You may withdraw from the study at any time without penalty.

For your safety, and those of others on the road, you will not be allowed to drive a vehicle after the study until you have had a sufficient period of sleep. At the completion of the study, you will either remain at APG for a sleep period or you will be driven back to Quantico to your place of residence depending upon the decision made by your command.

Most of the risks that you will encounter during this study are typical of the risks you would encounter in the performance of your duties as a Marine during field exercises. These risks include muscle strains, cuts, abrasion, and injuries that might result from trips or falls. There is also the risk of tick bites and the potential for Lyme Disease. You will be encouraged to use insect repellent which will be available at the test site, and we will ask that you inspect yourself frequently for ticks.

Testing will continue if it should rain during the 52 hour test period; however, testing will be postponed in the event of lightning or thunder.

Under no conditions will you be exposed to hazardous sound levels. Sound levels will be adjusted for your comfort and will not exceed maximum allowable limits (85dBA for eight hours continuous exposure).

You should be aware that an HMD can cause visual rivalry along with disorientation, dizziness, and nausea. If any of these symptoms should occur you should notify the lane walker immediately.

Any photographs or videos taken during the study will be processed so as to conceal your identity by masking your face and name tag. All data collected during the study will be considered privileged and held in confidence.

During this study you will receive training and experience in the use of equipment and information displays which are similar to those provided in the Land Warrior system. Although the tests we will administer and the questions we will ask may seem redundant and bothersome at times, your responses are extremely valuable and will have a major influence on the design and use of this equipment and information displays in the future battlefield.

APPENDIX B. MULTIPLE AFFECT ADJECTIVE CHECK LIST – REVISED (MAACL-R)

MULTIPLE AFFECT
ADJECTIVE CHECK LIST

DIRECTIONS: On the next sheet you will find words which describe different kinds of moods and feelings. Mark an X in the boxes beside the words which describe how you **feel right now.** Some of the words may sound alike, but we want you to check all the words that describe your feelings. Work rapidly.

PA SS

1 ☐ active
2 ☐ adventurous
3 ☐ affectionate
4 ☐ afraid
5 ☐ **agitated**
6 ☐ agreeable
7 ☐ aggressive
8 ☐ alive
9 ☐ alone
10 ☐ amiable
11 ☐ amused
12 ☐ angry
13 ☐ annoyed
14 ☐ awful
15 ☐ bashful
16 ☐ bitter
17 ☐ blue
18 ☐ bored
19 ☐ calm
20 ☐ cautious
21 ☐ cheerful
22 ☐ clean
23 ☐ complaining
24 ☐ contented
25 0 contrary
26 ☐ **cool**
27 ☐ cooperative
28 ☐ critical
29 ☐ cross
30 ☐ **cruel**
31 ☐ daring
32 ☐ desperate
33 ☐ destroyed
34 ☐ devoted
35 ☐ disagreeable
36 ☐ discontented
37 ☐ discouraged
38 ☐ disgusted
39 0 displeased
40 ☐ energetic
41 ☐ enraged
42 ☐ enthusiastic
43 ☐ fearful
44 ☐ fine
45 ☐ fit
46 ☐ **forlorn**
47 ☐ **frank**
48 ☐ free
49 ☐ friendly
50 ☐ frightened
51 ☐ furious
52 ☐ lively
53 ☐ gentle
54 ☐ glad
55 ☐ gloomy
56 ☐ good
57 ☐ **good-natured**
58 ☐ **grim**
59 0 **happy**
60 0 healthy
61 ☐ hopeless
'62 ☐ hostile
63 ☐ impatient
64 ☐ incensed
65 ☐ indignant
66 ☐ inspired
67 ☐ interested
68 ☐ irritated
69 ☐ jealous
70 ☐ joyful
71 0 kindly
72 ☐ lonely
73 ☐ **lost**
74 ☐ loving
75 ☐ low
76 ☐ lucky
77 ☐ mad
78 ☐ mean
79 ☐ meek
80 ☐ merry
81 ☐ **mild**
82 ☐ miserable
83 ☐ nervous
84 ☐ obliging
85 ☐ offended
86 ☐ outraged
87 ☐ panicky
88 ☐ patient
89 ☐ peaceful
SO ☐ pleased
91 ☐ pleasant
92 ☐ polite
93 ☐ powerful
94 ☐ quiet
95 ☐ reckless
96 ☐ rejected
97 ☐ rough
98 ☐ sad
99 ☐ safe
100 ☐ satisfied
101 ☐ secure
102 ☐ shaky
103 ☐ shy
104 ☐ soothed
105 ☐ steady
106 ☐ stubborn
107 ☐ stormy
108 ☐ strong
109 ☐ suffering
110 ☐ sullen
111 ☐ sunk
112 ☐ sympathetic
113 ☐ tame
114 0 tender
115 ☐ tense
116 0 terrible
117 ☐ terrified
118 ☐ thoughtful
119 ☐ timid
120 ☐ tormented
121 ☐ understanding
122 ☐ unhappy
123 ☐ unsociable
124 ☐ upset
125 ☐ vexed
126 ☐ warm
127 ☐ whole
128 ☐ wild
129 ☐ willful
130 ☐ wilted
131 ☐ worrying
132 ☐ young

APPENDIX C. SUBJECTIVE STRESS SCALE

SUBJECTIVE SCALE

Circle one word that best describes how you feel right now.

Wonderful

Fine

Comfortable

Steady

Not Bothered

Indifferent

Timid

Unsteady

Nervous

Worried

Unsafe

Frightened

Terrible

In Agony

Scared Stiff

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APPENDIX D. SPECIFIC RATING OF EVENTS SCALE

RATING OF EVENTS - SPECIFIC

1. The scale below represents a range of how stressful an event might be. Put a check mark touching the line (✓) to rate how much stress you are experiencing right now.

Not' at All Stressful	**Most Stress Possible**

0 10 20 30 40 50 60 70 80 90 100

2. At what number value does the check mark touch the line?

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APPENDIX E. STANFORD SLEEPINESS SCALE

Degree of Sleepiness	Scale Rating
Feeling active, vital, alert, or wide awake	1
Functioning at high level buts not a peak; able to concentrate	2
Awake, but relaxed; responsive but not full alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleep, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7
Asleep	X

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APPENDIX F. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION – TASK LOAD INDEX (NASA-TLX)

7. SUBJECT INSTRUCTIONS: SOURCES-OF-WORKLOAD EVALUATION

Throughout this experiment the rating scales are used to assess your experiences in the different task conditions. Scales of this sort are extremely useful, but their utility suffers from the tendency people have to interpret them in individual ways. For example, some people feel that mental or temporal demands are the essential aspects of workload regardless of the effort they expended on a given task or the level of performance they achieved. Others feel that if they performed well the workload must have been low and if they performed badly it must have been high. Yet others feel that effort or feelings of frustration are the most important factors in workload; and so on. The results of previous studies have already found every conceivable pattern of values. In addition, the factors that create levels of workload differ depending on the task. For example, some tasks might be difficult because they must be completed very quickly. Others may seem easy or hard because of the intensity of mental or physical effort required. Yet others feel difficult because they cannot be performed well, no matter how much effort is expended.

The evaluation you are about to perform is a technique that has been developed by NASA to assess the relative importance of six factors in determining how much workload you experienced. The procedure is simple: You will be presented with a series of pairs of rating scale titles (for example, Effort vs. Mental Demands) and asked to choose which of the items was more important to <u>your</u> experience of workload in the task(s) that you just performed. Each pair of scale titles will appear on a separate card.

<u>Circle the Scale Title that represents the more important contributor to workload for the specific task(s) you performed in this experiment.</u>

After you have finished the entire series we will be able to use the pattern of your choices to create a weighted combination of the ratings from that task into a summary workload score. Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any *correct* pattern: we are only interested in your opinions.

If you have any questions, please ask them now. Otherwise, start whenever you are ready. Thank you for your participation.

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Appendix A.

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	*Perfect/Failure*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

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Appendix D.

Subject ID: ____________ Date: ____________

SOURCES-OF-WORKLOAD TALLY SHEET		
Scale Title	*Tally*	*Weight*
MENTAL DEMAND		
PHYSICAL DEMAND		
TEMPORAL DEMAND		
PERFORMANCE		
EFFORT		
FRUSTRATION		

Total count = ____________

(NOTE - The total count is included as a check. If the total count is not equal to 15, then something has been miscounted. Also, no weight can have a value greater than 5.)

Appendix E.

Subject ID: ____________ Task ID: ____________

WEIGHTED RATING WORKSHEET			
Scale Title	*Weight*	*Raw Rating*	*Adjusted Rating (Weight X Raw)*
MENTAL DEMAND			
PHYSICAL DEMAND			
TEMPORAL DEMAND			
PERFORMANCE			
EFFORT			
FRUSTRATION			

Sum of "Adjusted Rating" Column = ________

WEIGHTED RATING =
[i.e., (Sum of Adjusted Ratings)/15]

Frustration

or

Effort

Performance

or

Mental Demand

Performance

or

Temporal Demand

Mental Demand

or

Effort

Mental Demand

or

Physical Demand

Effort

or

Physical Demand

Frustration

or

Mental Demand

Appendix C.

Subject ID: ______________ Task ID: ______________

RATING SHEET

MENTAL DEMAND

Low High

PHYSICAL DEMAND

Low High

TEMPORAL DEMAND

Low High

PERFORMANCE

Good Poor

EFFORT

Low High

FRUSTRATION

Low High

17

Appendix B.

Sources-of-Workload Comparison Cards

Effort or Performance	Temporal Demand or Frustration
Temporal Demand or Effort	Physical Demand or Frustration
Performance or Frustration	Physical Demand or Temporal Demand
Physical Demand or Performance	Temporal Demand or Mental Demand

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APPENDIX G. GENERAL INFORMATION QUESTIONNAIRE

ID # ___________

GENERAL INFORMATION QUESTIONNAIRE

Please answer all questions by filling in the blanks as completely as possible. All information will be kept strictly confidential. The information is important for test purposes and will not be used for any other purpose.

1. SSN _______________ 2. Today's Date ___________

3. Time ___________

4. MOS Primary ________ Time in MOS ______ ______ (years) (months)

Secondary ________ Time in MOS ______ ______ (years) (months)

5. Length of service _____ _____ (years) (months)

6. Date of Birth ___________

7. Present Pay Grade __________

8. Education completed:
High School _____ (years)
College _____ (years)
Grad School _____ (years)

9. Height ________

Weight ________

10. On the scale below, place a mark on the line to indicate how important the completion of the study requirements are to you.

0	10	20	30	40	50	60	70	80	90	100
not important at all									extremely important	

Please explain why:____

____

11. On the scale below, please rate how willing you are to participate in this study:

0	10	20	30	40	50	60	70	80	90	100
not at all									very willing	

12. PHYSICAL ACTIVITY

a. In regard to overall physical activity, how would you describe your life?

Very Inactive	Somewhat Inactive	Average	Active	Very Active
______	______	______	______	______

b. How many times per week do you engage in any regular physical activity (like jogging, bicycling, etc.) long enough to work up a sweat?

None	1	2	3	4	5	6	7 or more
___	___	___	___	___	___	___	___

13. PHYSICAL FITNESS: Compared to others of your age and sex, how would you rate your:

	Far Below Average	Below Average	Average	Above Average	Far Above Average	
a. Endurance	______	______	______	______	______	b. Sprint
Speed ______	______	______	______	______		
c. Strength	______	______	______	______	______	
d. Flexibility	______	______	______	______	______	

14. To the best of your recollection, list your most recent Army Physical Fitness Test (APFT) raw scores and APFT total points:

a. Number of Push-ups ________

b. Number of Sit-ups ________

c. Two-mile run time (min : sec) ____:____

d. Total APFT Points ________

15. Present overall health: (check one)

(1) _____ excellent

(2) _____ good

(3) _____ fair

(4) _____ poor

16. Have you experienced any of the following health symptoms?:

	Yes	(Time Occurred)	No	Don't Know
Frequent or severe headaches	___	___________	___	___
Dizziness or fainting spells	___	___________	___	___
Sinusitis (Sinus headache)	___	___________	___	___
Head injury	___	___________	___	___
Palpitation or heart pounding	___	___________	___	___
Heart trouble	___	___________	___	___
High or low blood pressure	___	___________	___	___
Loss of memory or amnesia	___	___________	___	___
Black-outs	___	___________	___	___
Excessive worrying or anxiety	___	___________	___	___

17 List any other health problems currently affecting you:

____

____

____

18. Are you **presently** taking any medicines or drugs for medical reasons?

_____ yes _____ no

If yes, what kind(s)?

____

For what condition?

____

Date you began using this medicine or drug ______________________

19. Other than those listed in question 18, have you taken medicines or drugs for medical reasons at any time during the past 3 months?

_____ yes _____ no

If yes, what kind(s)?

____

For what condition?

____

____

20. Are you presently receiving any hormone treatments (not including birth control pills)? ______ yes ______ no

____

If yes, what kind(s)?

____

For what condition?

____

21. Other than those listed in question 20, have you received any hormone treatments at any time during the past 3 months?

_____ yes _____ no

If yes, what kind(s)?

____

For what condition?

____

22. How many hours of sleep do you normally get on week nights? _______ on weekends? _______

23. Are you following any special diet right now? (check one)

_____ yes _____ no

If yes, explain:

____

____

24. Have you ever had any surgery that affected your reproductive system? (check one)

_____ yes _____ no

If yes, explain:

____

____

25. Do you find you are over tired: (check one)

(1) _____ never
(2) _____ occasionally
(3) _____ frequently

26. Do you consider yourself: (check one)

(1) _____ right-handed
(2) _____ left-handed
(3) _____ ambidextrous (right for some tasks, left for others)

27. Which hand do you use to write with: (check one)

_____ right _____ left

28. Do you smoke cigarettes? (check one) _____ yes _____ no

If yes, approximately how many per day? _____

29. Are you pregnant? (check one) _____ yes _____ no

30. At what age did you have your first period? ________

31. Are you taking birth control pills? _____ yes _____ no

32. If you are presently taking birth control pills:
(1) what brand of pills are you taking: ___________________
(2) how long ago did you start taking birth control pills _________

33. If your are not presently taking birth control pills:
Have you recently stopped taking birth control pills
(within the last 3 months): _____ yes _____ no

34. Have you ever had a child? _____ yes _____ no
If yes, how many? ________

35. Are your periods: (check one)
(1) _____ always regular and predictable
(2) _____ usually regular and predictable
(3) _____ irregular and unpredictable
(4) _____ other. Explain:

____

____

36. Have you missed a period during the last 3 months?
_____ yes _____ no
Do you miss periods: (check one) (1) _____ never
(2) _____ occasionally
(3) _____ frequently

37. Do you usually keep track of when your next period will start? (check one)
______ yes ______ no

If yes, what method(s)
Do you use?
(1) _____ memory
(2) _____ mark calendar
(3) _____ count birth control pills
(4) _____ other. Explain

____

____

38. What was the starting date of your most recent menses (first day of your period)?
____

39. Do you suffer from menstrual cramps or other menstrual symptoms that are severe enough to keep you from performing your regular duties? (check one)
(1) _____ never
(2) _____ occasionally
(3) _____ frequently

40. Do you use an I.U.D. (intra-uterine device)? _____ yes _____ no

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APPENDIX H. LIFE EVENTS FORM I

LIFE EVENTS FORM I

1. Check the appropriate response: "I have recently experienced:"

   Unusually low stress ______
   Mild stress ______
   Moderate stress ______
   High stress ______
   Unusually high stress ______

2. Have you recently experienced any events having an impact on your life? Yes ____ No ____
   Please list them and indicate them as positive or negative by placing them in the corresponding column:

POSITIVE	DATE EVENT OCCURRED

NEGATIVE	DATE EVENT OCCURRED

3. How would you rate the way you handled any events that occurred?

   Very well ______
   Well ______
   Adequate ______
   Poorly ______
   Very Poorly ______

4. "Considering all that has happened recently, my resources for responding to the events were:"

   More than adequate ______
   Adequate ______
   Less than adequate ______

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APPENDIX I. SITUATIONAL SELF-EFFICACY SCALE (SSE)

SSE

1. On a scale from 1 to 10, how confident are you in your ability to deal with **today's experiences**? Please circle one of the numbers below.

1	2	3	4	5	6	7	8	9	10
Not at all confident									Extremily confident

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